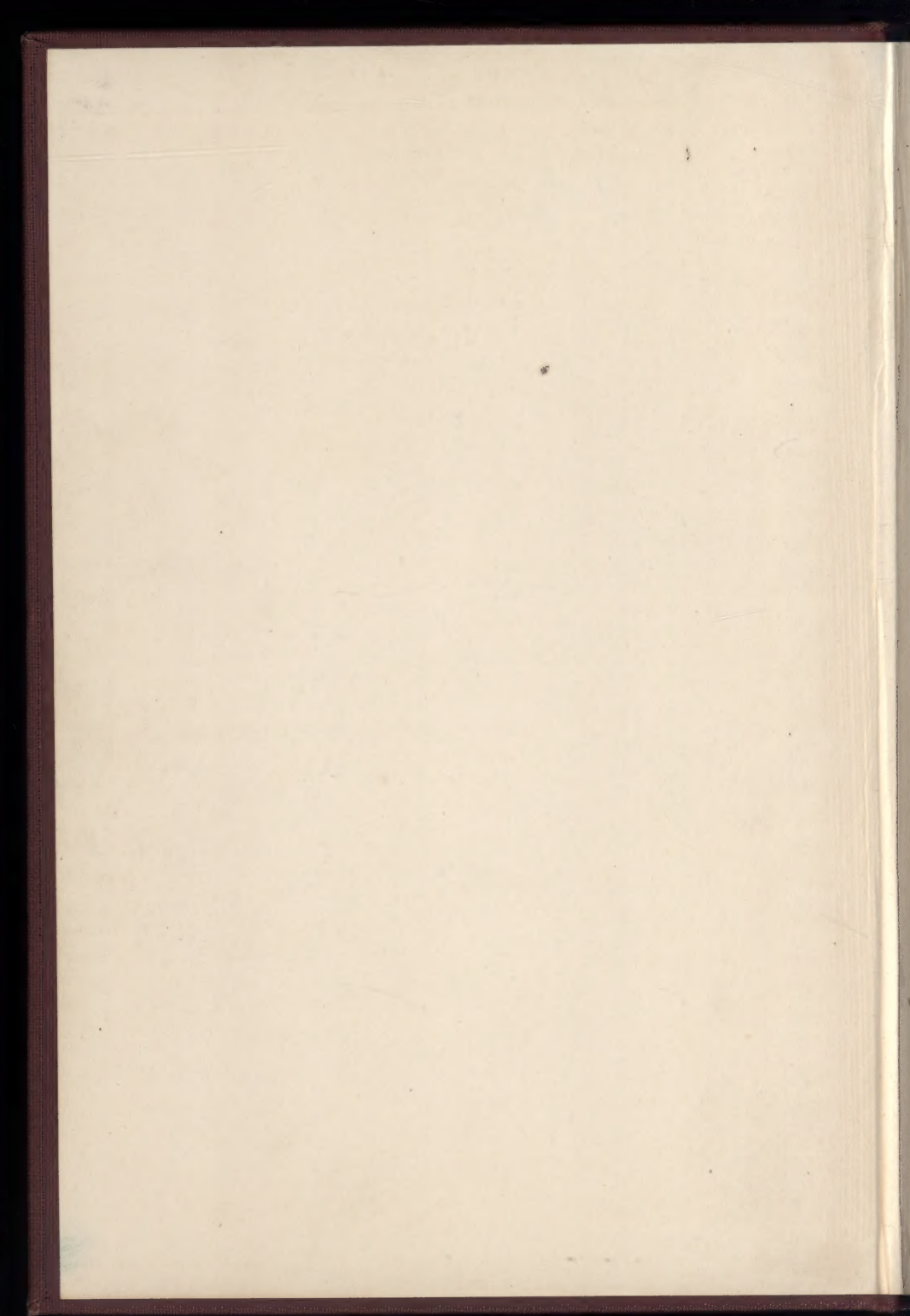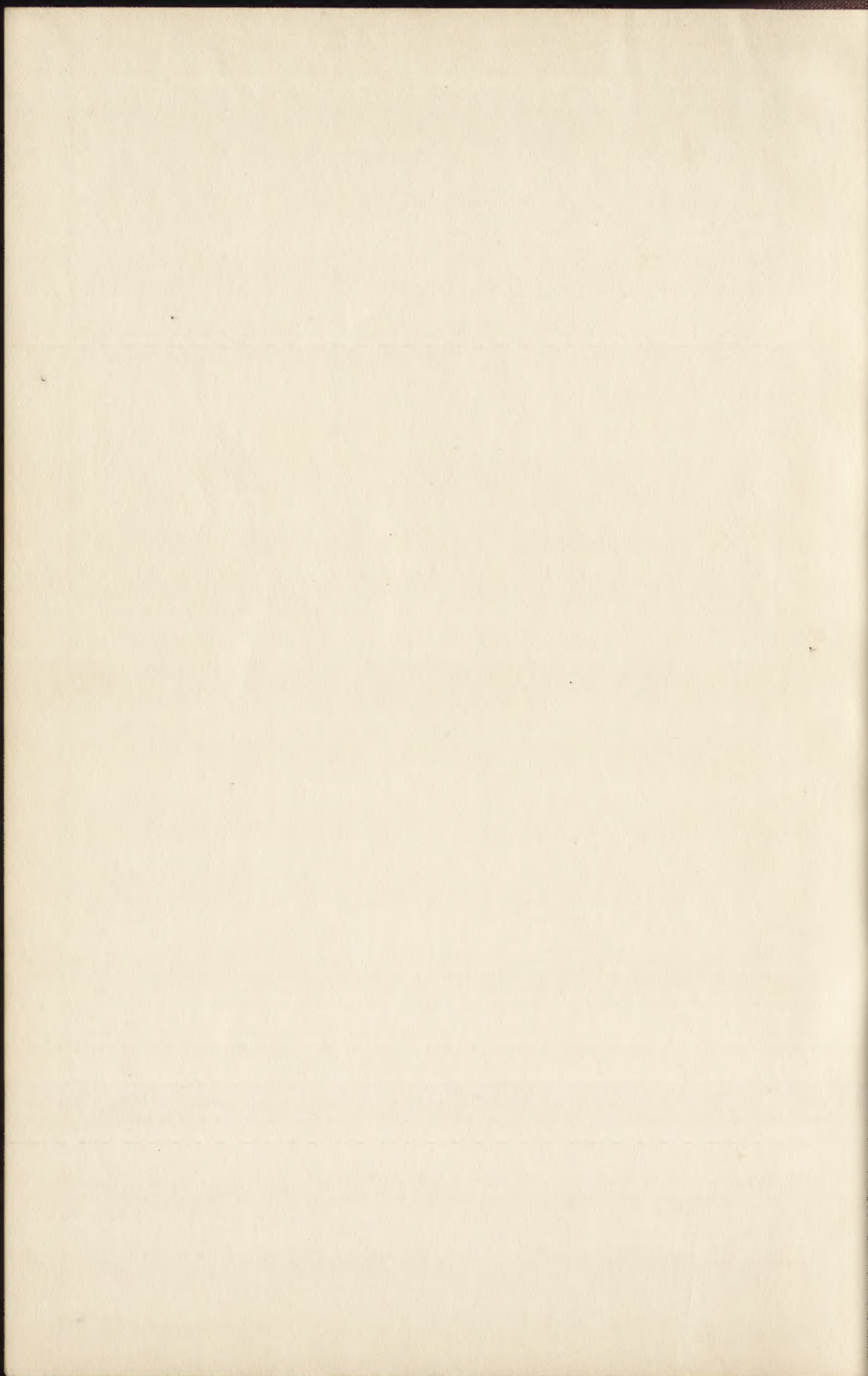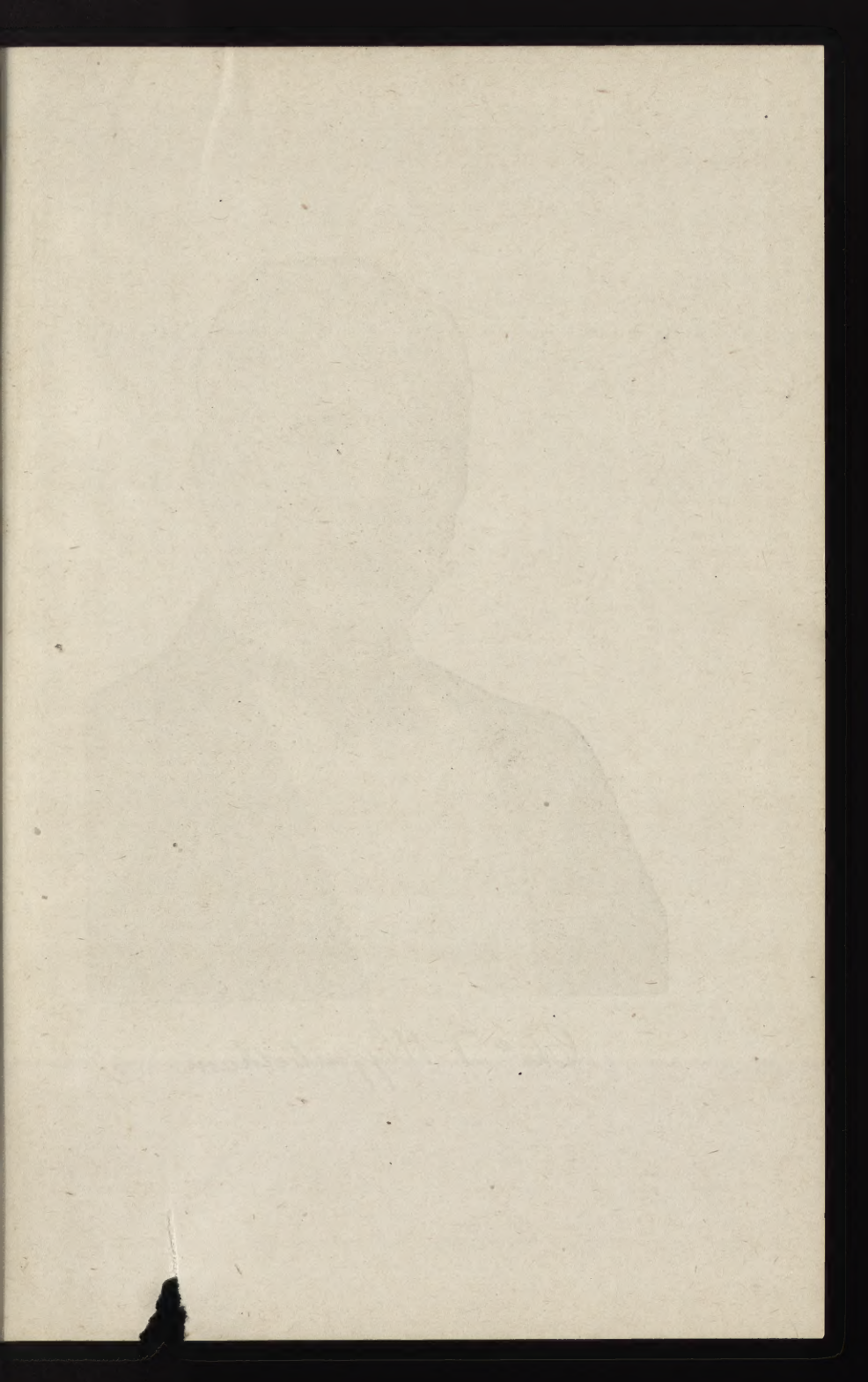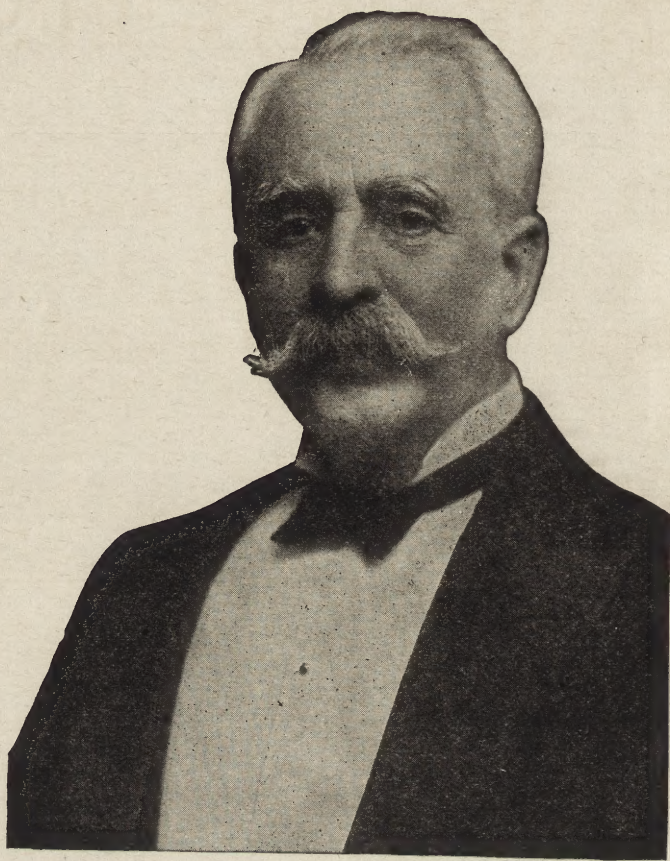# Precision
Time Measures
Higginbotham

$25—

Francis C. Fowler

Chas T Higginbotham

PRECISION
TIME MEASURES

THEIR

CONSTRUCTION AND REPAIR

A MANUAL OF THE THEORY AND MECHANICAL LAWS GOVERNING
THE CONSTRUCTION OF TIMEKEEPING MACHINES AND
ACCEPTED METHODS OF THEIR MAIN-
TENANCE AND REPAIRS.

———

By CHARLES T. HIGGINBOTHAM

Consulting Superintendent of the South Bend Watch Co.   Author of "Short
Talks to Watchmakers," "Jeweled Bearings for Watches," Etc.

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WITH NUMEROUS ILLUSTRATIONS AND DIAGRAMS.

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CHARLES THOMAS HIGGINBOTHAM.

Charles Thomas Higginbotham was born in County Wexford, Ireland, in 1840, being the youngest son of Joseph Higginbotham, a watchmaker. In 1845 the latter brought his family to New York and settled in that city. Following the customs of those days, the lad was "bound out" to learn the trade of watchmaker and jeweler, when he reached the age of fifteen, being apprenticed to a watchmaker in Logansport, Ind.

Previous to his apprenticeship at the age of fifteen, he received the usual tuition of the public schools of that time; but he did not consider his education finished with his school days. Always of a studious nature, with a natural aptitude for the scientific and mechanical, he became unusually well read and widely informed on many topics in addition to watchmaking. He also had a good working knowledge of higher mathematics, astronomy and drawing, acquiring them as incident to his work.

In 1861 he returned to New York and at once enlisted in the Nineteenth New York Infantry, in which he served until 1863.

In 1868 he became a silent partner with M. Higginbotham & Horton, 61 Montgomery St., Jersey City, N. J., where he remained for about three years, repairing watches. In 1871 he was head watch and chronometer maker with Giles, Wales & Co., 9 Maiden Lane, New York City, who were then selling agents for the Marion Watch Company.

In 1873 he entered the employ of the New York Watch Company which afterwards became the Hampden Watch Company, at Springfield, Mass., where he became the master watchmaker.

In 1885 he became superintendent of the Seth Thomas Watch Company, Thomaston, Conn. In 1900 he went with the Illinois Watch Company, Springfield, Ill., as superintendent. In 1904 he was engaged by the South Bend Watch Company, South Bend, Ind., as superintendent, which position he held until 1908, when he gave up the active duties of superintendent and became consulting superintendent. This position he held until the time of his death, Aug. 27, 1915.

His proficiency as a teacher was very marked and his sympathy for and desire to help the young men under him were so evident that he readily created friends of all with whom he came in contact professionally. It was this characteristic which made him so welcomed at the meetings of the retail jewelers' associations during the last twelve years, and his addresses at these meetings made him always prominent on their programs. Finding that these talks were always followed by requests for copies by the retailers who had heard them, the South Bend Watch Company began to issue them as pamphlets for free distribution under the general title of "Short Talks to Watchmakers."

In 1913, at the suggestion of the general manager of the watch company, he undertook to rearrange and rewrite them as a complete treatise, adding much new matter and many drawings, and treating the entire subject in consecutive order, as it was his desire to make the work so plain and simple as to be serviceable to the youngest member of the trade, and at the same time so complete as to serve as a work of reference for those who have long ceased to need instructions.

His sole purpose in writing this treatise was to do away with the mysteries of watchmaking for those who are so situated that they cannot attend the technical schools, or who for various reasons must educate themselves. In this undertaking he was given the widest latitude by his company and the publishers and he personally made the drawings to illustrate this work. He was revising the last chapter at the time of his death.

He was a member of the Bureau of Awards at the Louisiana Purchase Exposition at St. Louis; also at the Panama Exposition in Buffalo. He was a Mason of high rank, 32d degree, which at that time was as high as one could go in this country, the 33d degree being given in England. After he went East the second time and located in Springfield, Mass., he gave up his activities with the Masons, as his watch factory work left him no leisure for such affiliations. While in Thomaston, Conn., he was made commander of the Grand Army Post.

CHAPTER I.

THE MAINSPRING.

The mainspring is the source of power. It is to the watch what steam is to the locomotive. Too much care cannot be bestowed upon the selection of material and manufacture of the mainspring. It is not our purpose to go into the manufacture of this most important part of a watch, but we can not urge too strongly the fact that the best is not too good where accurate time is desired.

There are several good makes of mainsprings on the market. There are also several poor makes. It is not economy to use the latter, simply because they can be had at a low price. The trouble caused by breakage, loss of elasticity and other shortcomings make the purchase of the inferior article anything but economy. Add to this the fact that accurate time in the true sense of the expression can never be obtained where a poor mainspring is the motive power and you have the strongest incentive for the use of the best spring that can be had, especially where fine time is required.

The work imposed upon a mainspring is stupendous in proportion to the little strip of metal of which it consists. A spring in an 18 size watch of the ordinary type, when wound to the top is capable of lifting about one pound suspended by a cord around the barrel, and if of proper proportion and correct temper will lift about two-thirds of that amount at the end of a 24-hour run. A good spring, properly proportioned to the watch should run it about 34 hours. This gives the most effective part of the spring for the day's run of 24 hours. The accompanying sketches illustrate the action of a mainspring under ordinary conditions.

Fig. 1 shows the appearance of the mainspring when wound to the top. The coils are drawn close together, and if

it is wound very tightly there is a sort of adhesion produced
by their friction on each other.   This is why a spring may be
wound so tightly that it will not transmit sufficient power to
a watch train to keep the balance in motion, with the result
that the watch stops. In fact any watch having no stop work
and not provided with a recoil click will not impart full mo-
tion to the balance until it has run 20 to 50 minutes after
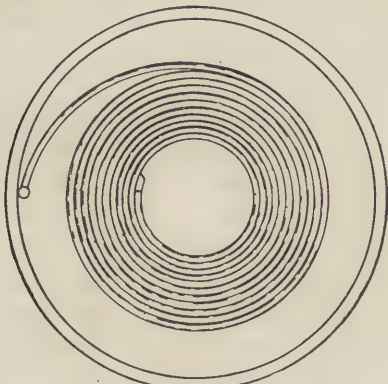winding. It takes about this length of time to release the

Figure 1.

coils of the mainspring from each other sufficiently to de-
liver their full power.

Fig. 3 shows what takes place as the spring unwinds. In
this condition several coils of the spring lie against the inside
wall of the barrel chamber, impinging against each other
with considerable force. To overcome this, quite a percent-
age of the spring power is required, thus reducing the
amount transmitted to the watch train.   As the spring still
continues to unwind, the contact of the coils with each other
is extended until the majority of the coils come together all
the way around, eccentric with the barrel and touching the
inside of the wall at one point, thus forming—so to speak—
a secondary barrel inside the primary one, as shown in
figure 4.

At this point the impingement of the coils offers a great
deal of resistance to the unwinding of the spring, and a series
of sudden increases of power occur, each followed by a
gradual decrease as the coils struggle, so to speak, for
release.

The action of the spring when being wound is entirely dif-
ferent. While the winding takes place there is comparatively
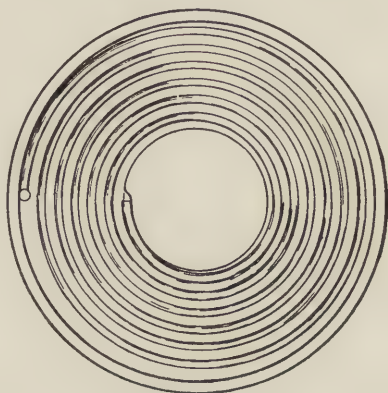little friction between the coils. See Fig. 2. When a spring

Figure 2.

is wound half way up it delivers, for a time, considerably
greater power than when, after being wound to the top, it
is let down to the same point.

It is exceedingly interesting to watch this action which
can readily be done by skeletonizing a barrel for the purpose.

There are some beautiful and exceedingly useful laws
governing the action and proportions of a mainspring. One
of these is quite at variance with an old rule, which we have
all heard and most of us followed, that the interior of a bar-
rel should be occupied by one-third barrel arbor, one-third
space, one-third mainspring. When the rule is applied this
is generally taken to mean radial measurements from the

center to the inside wall of the chamber against which the spring lies. Now it happens that there is only one part of this rule that is correct, and that is the dimensions of the barrel arbor hub. In practice this will be always found about one-third the diameter of the chamber; but instead of dividing that portion of the barrel not covered by the arbor hub into two equal spaces radially, it should be divided into two equal areas, of which the mainspring should occupy one. It will be seen that if the mainspring occupies half the area
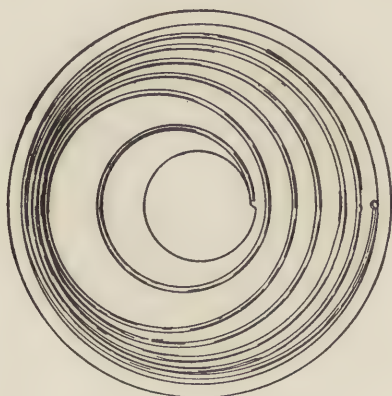

Figure 3.

outside the arbor hub that that condition will prevail at all times. Whether the spring is wound up closely about the arbor, part way down, or completely down and lying against the inside of the chamber. When that condition prevails in a barrel the watch will run the greatest number of hours which that spring can be made to carry it. Either lengthening or shortening the spring will decrease the number of hours. Besides this there will be much less rubbing of the coils, one upon the other.

   To determine accurately the location of a circle that will divide the space into two equal areas involves a somewhat

complicated problem, but fortunately it happens that when
the barrel arbor is one-third the diameter of the chamber we
have a constant which gives a very close approximation to
this line. A circle drawn ¾ the diameter of the barrel cham-
ber will divide the space outside the hub into two equal areas,
so that the watchmaker may never be at a loss to know when
his mainspring is of the proper length. Simply describe a cir-
cle three-quarters the radius of the chamber, inside of it.

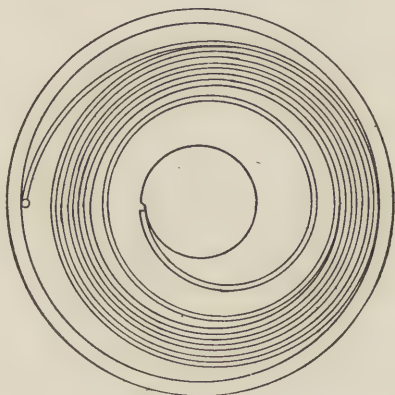Of course, when the mainspring is wound up tight around

Figure 4.

the barrel arbor, although it covers the same area, it will
contain a greater number of coils than when it is let down
against the wall. Here comes another law of the mainspring:
The difference between the number of coils when the spring
is wound to the top, and when it is let down, is exactly the
number of turns the barrel will give, and this law holds good
whether or not, the mainspring is properly proportioned.
These two rules provide us with means for calculating the
thickness and length of a mainspring before trying it in the
barrel. It is of the greatest importance in watch factories
where it is necessary that everything in connection with the
model in process of construction be accurately determined in

advance. It involves quite a little calculation to determine the length and thickness, in view of which it may be just as well for the repairer to mark his barrel and determine the dimensions of his spring by means of that mark in connection with the difference in the number of coils when wound and unwound.

Fig. 5 will illustrate the location of a circle dividing the space outside the hub into two equal circles. In this figure A is the barrel, B the barrel arbor, C is a circle dividing the
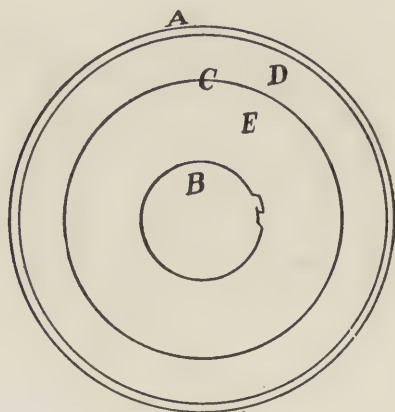

Figure 5.

space into two equal areas, D and E. The circle C should be exactly ¾ the diameter of the barrel chamber. In fitting a mainspring see that when the spring lies against the wall of the chamber, that its inner coil does not project much beyond the circle C. If this is attended to it necessarily follows that when the spring is wound up tight around the barrel arbor, its outer coil will not project beyond the circle C. Marking this circle with some sharp instrument, on the inside of the barrel can do no possible harm and will be an unerring guide in fitting a spring.

The barrel arbor hub should be snailed, as shown at B. The hook should not project beyond the thickness of the first coil of the mainspring. This avoids the formation of kinks in the spring when wound up close about the arbor, and obviates breakage. The arbor of the mainspring winder should be of the same shape and its hook the proper thickness for the same reasons.
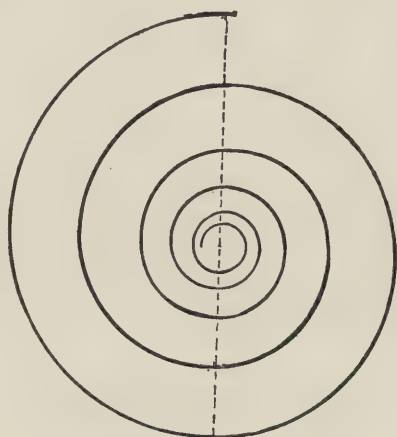

Figure 6.

In putting a spring into a barrel carefully avoid anything that would distort it. Use a mainspring winder both for putting it in and for removing it. The life of a spring at best, is limited, owing to the excessive strain to which it is constantly subjected. Putting any additional strain upon it by distortion injures its efficiency and shortens its life.

Many watch makers manifest extreme reluctance to remove a mainspring from a barrel when cleaning a watch, being deterred by fear that the spring will break as a result of removing and replacing it.

In this connection it is well to understand that the efficient life of all mainsprings is limited.

A mainspring in a watch is constantly in a state of high tension. While it is being wound the flexure of the spring displaces the molecules, those on the outside of each coil
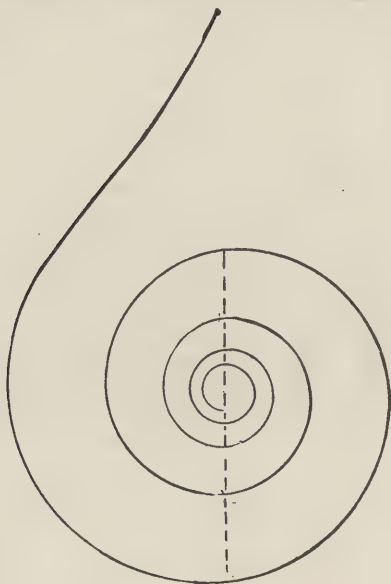

Figure 7.

are being separated, those on the inside are being compressed. While unwinding the order of this change is reversed. This strain being continued produces what is known as "Metal fatigue." This ultimately results in one or other of two conditions—it either loses its elastic force (sets) or it breaks.

When a spring is nearing the end of its life any additional strain put upon it is likely to hasten the end, hence, it sometimes happens that the strain incidental to removing and replacing a spring will cause a separation of the molecules

after it has been put back in the barrel that will result in breakage. This, however, should not deter the watch maker from removing a spring when putting a watch in order. The spring may not need removal for the purpose of cleaning it, but it should be taken out of the barrel for examination.

It is of the utmost importance that the spring should not be set—that it should possess the proper amount of elastic force. This cannot be determined without removal from the
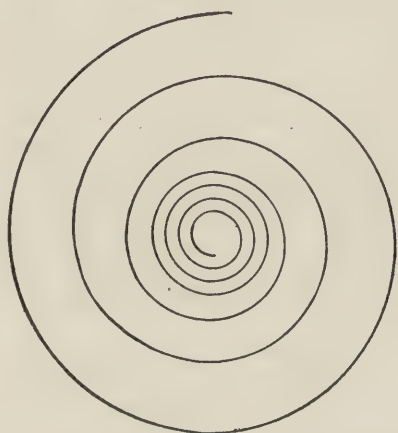

Figure 8.

barrel. True, the removal of a spring may possibly bring about a rupture, but if carefully done the possibility is a remote one.

The following are a few "dont's" that should be carefully observed:

Don't pull a mainspring out of its barrel by grasping the center coil with pliers or tweezers.

Don't replace it by inserting the brace in position, or by hooking the outside eye, then backing the spring into the barrel.

Don't bend or distort the spring in the least while cleaning.

One of the best methods of cleaning a spring is to fold a strip of chamois over the outside coil and move it along carefully till the inside coil is reached, being careful not to bend the spring while doing so.

In removing or replacing a spring in its barrel, always use a mainspring winder.
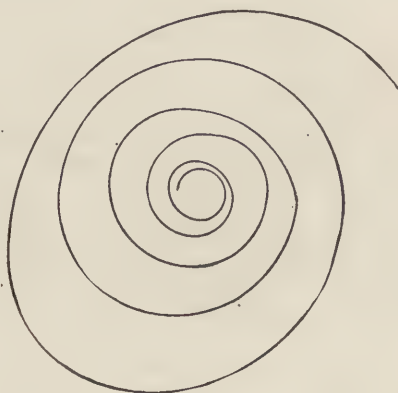

Figure 9.

If these precautions are followed there is very little danger of breakage, and even if it should break it is simply evidence that it had reached the end of its natural life and should be replaced.

The greatest evil to be feared in a mainspring is setting. Breakage is an accident that manifests itself without the possibility of a mistake. Setting is an insidious enemy that may creep in unobserved.

As has been said, in cleaning a watch the mainspring should be taken out and examined. An ordinary spring when removed from the barrel should open to the diameter of 14% of its length, measured as indicated in Fig. 6. If a

resilient spring it should measure from the second coil, 11% of its length, as shown in Fig. 7, this would be, for an 18 size watch, about 3″ for the ordinary one, 2½″ for the resilient.

The coils of a spring when in good condition should form a true spiral with increasing distances between its coils, from the inside to the outside, as shown in Fig. 6.

If it is distorted—see Fig. 9—it is unfit for use, for the reason that it is a sure indication of soft spots or of having been subjected to improper treatment.

A spring as shown in Fig. 8, although it may open well, will not give good results. It will be noticed that in this spring the inner coils form an equi-distant coiled spiral, which indicates weakness or want of temper in that part of the spring, the balance of the spring being of the proper form. As this spring unwinds the outer coils first come to rest against the inside of the barrel chamber wall. These coils are then inactive, giving no power. Upon the weaker, inner coils devolves the work of carrying the train and balance; the result being that the motion falls off.

Some manufacturers have produced a spring made of a tapering strip of steel, thicker at the center and thinner at the outer end, but its advantage—if any—did not compensate for its cost of manufacture.

CHAPTER II.

THE CALCULATION OF WATCH TRAINS.

When a watch is wound a certain amount of power is used to place the mainspring in a state of tension. This is, in effect, the storing of power. That power is conveyed to the balance through a train of wheels and pinions. These wheels and pinions are in reality a series of levers, the power being applied much nearer the fulcrum than is the resistance offered. The result of this repeated subdivision is that at the extreme end of the train of wheels the power exerted is very much less than originally delivered by the mainspring.

In calculating any train of wheels it is necessary to determine the number of revolutions required to be given by the last wheel in the train for one revolution of the first. This being determined, its accomplishment is as follows:

Select a number of members to convert the power into motion. In a watch train we have the barrel, center, third, fourth and escape wheels. The latter has fifteen teeth. Each tooth delivers two impulses, by means of the pallets and fork to the balance. Let us assume that the barrel is required to give six revolutions to the center wheel for one of its own and that the balance is required to give 18,000 vibrations for one revolution of the center wheel. This is to say, the balance must give 108,000 vibrations to one revolution of the barrel, or main wheel.

The number of leaves for each pinion may be selected at will, but the numbers of the wheel teeth must be in proportion to them. In this case we shall select as follows: Center pinion, 12; third pinion, 10; fourth pinon, 10; escape pinion, 8.

We have decided that the barrel should give six revolutions to the center wheel. Consequently it must have for

teeth, six times the number of leaves of the center pinion, or 72. Now the center must impart to the balance 18,000 vibrations for one of its revolutions. The escape having 15 teeth and imparting two vibrations to the balance for each tooth gives the balance 30 vibrations for each of its revolutions. Dividing 18,000 by 30 gives us 600, which is the number of revolutions that the escape wheel must give for one of the center wheel. Multiply together the leaves in the third, fourth, and escape we have 8,000. This multiplied by the number of revolutions of the escape wheel (600) gives us 480,000. Of this number we ascertain the prime factors which consist of eight twos, one three, and four fives. We now require numbers for teeth for the center, third, and fourth wheels. The prime factors just found are then divided into three groups in any way that may be seen fit, and each group multiplied together will give numbers for the wheels that will cause the escape to give the proper number of revolutions. Let us take for our first group four twos and one five. This will give us 80 teeth, which we will give to the center wheel. For our second group we will take two fives and one three, which gives us 75 for the third wheel. We now take the remaining factors, which are four twos and one five; this will give us 80 teeth for the fourth wheel

Proof: The center wheel will revolve the third pinion 8 times and the third wheel will rotate the fourth pinion 7½ times and the fourth wheel will turn the escape pinion 10 times. 7½ times 8 times 10 makes 600, which is the proper number of revolutions of the escape wheel.

The above may seem somewhat complicated at first sight, but it is really quite simple. The rule is as follows: Multiply the number of leaves of the pinions together with the number of revolutions required of the last member. Find the prime factors of the product and divide them into groups as required.

Inasmuch as modern watches invariably are so arranged that the fourth wheel gives 60 revolutions for one of the center in order to carry the seconds hand, it is only necessary in selecting your wheels to multiply the number of leaves in third pinion by 8 to get the number of teeth for the center wheel; to multiply the leaves of the fourth pinion by $7\frac{1}{2}$ for the teeth of the third wheel; and to multiply leaves
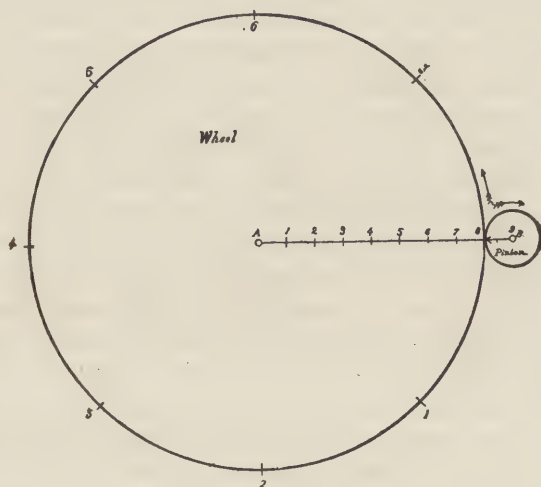

Figure 10.

of the escape pinion by 10 for the fourth wheel teeth. This is if an 18,000 train is required; but if it is a 16,000 train multiply the number of the escape leaves pinion by 9.

Watchmakers will at once see the value of this rule when they are required to replace lost wheels and pinions.

GEARING.—The attention of the student is invited to the study of the principles underlying all gearing, of whatever nature and for whatever purpose. One in particular is this: The pitch diameters of the various members, and the respective numbers of teeth should be in exact proportion. In

a watch, these members are usually wheels and pinions. In watches the gearing of a wheel into a pinion is called the depthing. Depthing is based upon the principle of two circular bodies revolving with their peripheries in contact. If it is desired that a wheel shall revolve the pinion 8 times for one of its own revolutions the diameter of the wheel to the pitch circle must be 8 times that of the pinion. See Fig 10.

The large circle is the pitch circle of the wheel; the small one, that of the pinion. A is the center of the wheel; B, the center of the pinion. The line connecting A and B is called the line of centers. We have divided this line into nine equal parts, of which the radius of the wheel embraces eight; that of the pinion one. The wheel is assumed to be moving in the direction indicated by one of the arrows and to be driving the pinion in the direction indicated by the other. As they revolve the part of the pinion in contact with the wheel at 8 will touch in succession the points 1, 2, 3, and so on around the large circle until when it again reaches 8 the pinion will have made eight complete revolutions. In other words the distances between two of the points around the large circle represent the circumference of the small one. This is precisely the condition that should prevail in a properly designed depthing.

ADDENDA.—The curved ends of both teeth and leaves project beyond their respective pitch circles; see Fig. 11. Their intermeshing is called the penetration of gearing. The amount that each projects beyond its pitch circle is called the addendum.

Before considering this feature it is well that we should give the technical names applied to the different parts and functions of a depthing.

PITCH CIRCLE.—The circle upon which the pitch of the wheel is measured and at which the curve of the teeth begins.

CIRCULAR PITCH.—The distance, measured on the pitch circle, from any point on a tooth to a similar point on the

next adjacent tooth. The circular pitch is determined by dividing the pitch circle by the number of teeth.

DIAMETRIC PITCH.—The diameter of the pitch circle divided by the number of teeth. The diametric pitch is used to a considerable extent for making calculations in depthing. Addenda are usually calculated from diametric pitch.
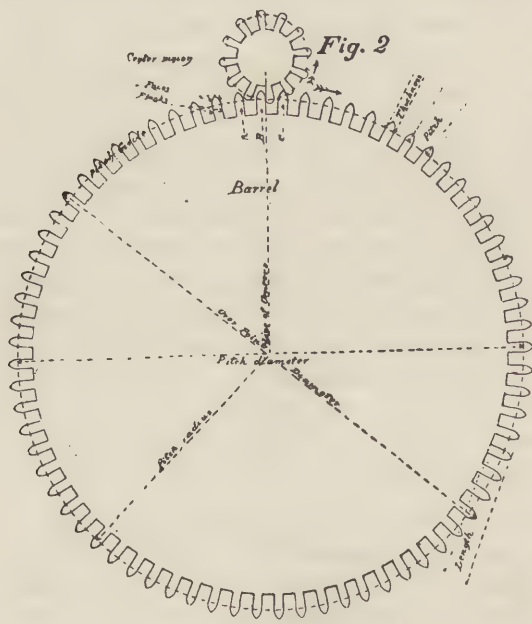

Figure 11.

FLANK.—That part which extends inward from the pitch circle to the base of the tooth.

A reference to Fig. 11 which gives the location of the different parts, will serve to fix these terms in the student's mind.

When the wheel is the driver and the pinion the driven, it is only the face of the wheel tooth and the flank of the

pinion leaf that come in contact with each other during the
action of the depthing. The action of the wheel tooth on the
pinion leaf should begin at the line of centers. The flanks of
tooth and leaf should both be in alignment with the line of
centers and with each other, as shown in Fig. 11. Here both
wheel and pinion are represented as moving in the direction
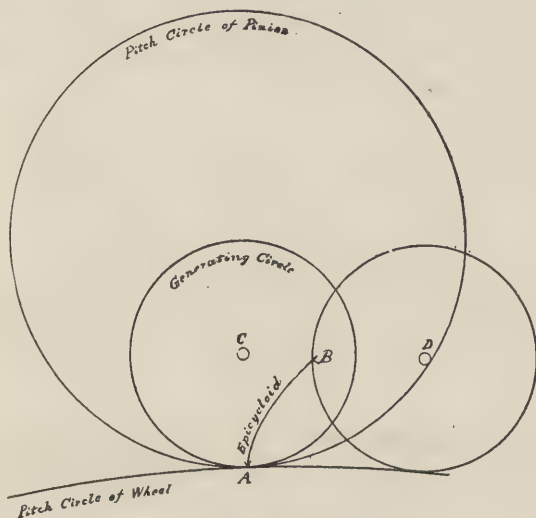indicated by arrows; the wheel driving. It is seen that the

Figure 12.

tooth A has not yet engaged a pinion leaf; tooth B has just
begun its engagement; tooth C is about to cease. It is evi-
dent therefore that during the entire impulse as delivered by
each tooth, it is—as has been previously said—the face of
the wheel tooth that impels by contact with the pinion leaf.
Under these conditions it matters little as to the form of he
face of the pinion leaf, but the form of the wheel tooth is of
paramount importance. The epicycloid is considered the best
shape for the face of a wheel tooth. The manner of produc-
ing this curve will be made clear by reference to Fig. 12, in
connection with the following description. An epicycloid is

developed by rolling one circle upon the circumference of another. The circle rolled upon the outside is called the generating circle. When the generating circle is rolled upon the inside, the resulting line is called a hypocycloid. These curves are traced by points located on the periphery of the generating circle. In Fig. 12, A is the point upon the generating circle. This is tangential with the pitch circle of the wheel when the center of the generating circle is at C. While it is being rolled to the position with its center at D, the point A will have traveled along the line marked epicycloid
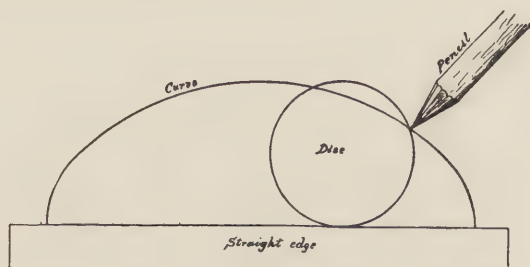

Figure 13.

and will have reached the point B. In developing the addendum of a wheel tooth the generating circle should be half the diameter of the pinion to its pitch circle. In developing the flank of a wheel tooth the developing circle should be half the diameter of the wheel to its pitch circle, but inasmuch as the hypocycloid thus developed is a radial line, it is unnecessary to determine it by a generating circle. The same is true of a flank of a pinion leaf.

A simple method of demonstrating the development of a curve by means of a generating circle is to fasten a straight edge to a board upon which a piece of paper has been attached. Now take a circular piece of wood and cut a small notch at any point of its edge—see Fig. 13. The point of the pencil held in the notch while revolving the disc along the straight edge will develop the curve as shown. This curve is

called a cycloid. If instead of a straight edge, the generating circle had been rolled along the arc of a circle, the curve would have been an epicycloid.

We will now give illustrations of the effects of improperly designed depthing. The drawings illustrating these are made from careful calculation and present the precise conditions that would prevail under similar circumstances in a watch.

Fig. 14 illustrates a deep depthing in which the wheel is three per cent too large. The lines marked pitch circles are
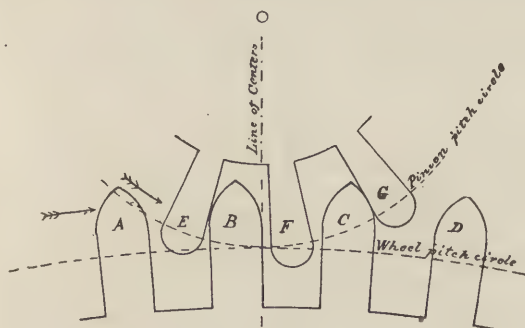

Figure 14.

the true circles for the pitches of the wheel and pinion. Here let me say that while the addenda of wheels and pinions may be slightly varied, the pitch circles are arbitrary and cannot be deviated from in the slightest. It will be noticed that the spaces of the pinion leaves begin as they should, at its pitch circle, while the beginning of the faces of the wheel teeth are considerably beyond its pitch circle. In fact they are just the amount beyond the pitch circle that the wheel is too large. The members are supposed to be moving in the direction indicated by the arrow, the wheel being the driver. Tooth A of the wheel is a considerable distance from its pinion leaf E. Tooth B. although its forward flank is along the line of centers, and should be at this point in contact with the leaf, as has been explained, has not yet come in contact with its

leaf F, although leaf F has already moved some distance beyond the line of centers. Furthermore one of the faces of tooth B is so close to a flank of leaf E that it almost abuts, and might cause the depthing to wedge. Tooth C is still in contact with its leaf G, although it should have ceased long before reaching this point. Tooth G has passed out of reach The effect of such a depthing in a watch would be to cause a variation in the power while the wheel was delivering its impulse; this variation would make itself manifest in the mo-
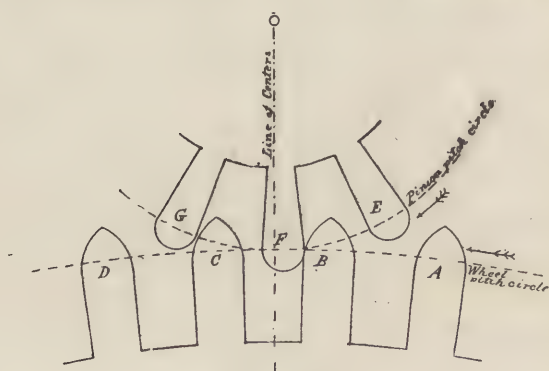

Figure 15.

tion of the balance. In other words a picking up and falling off of the motion would take place at intervals. There is, however, a still greater danger from a depthing with this defect. As seen, the tooth B is in greater danger of abutting the leaf E, in which case the watch would probably stop. A deep depthing can generally be detected by holding the wheel that is on the staff of the pinion that is being driven, and while thus held try the shake of the wheel which is the driver. By referring to Fig. 14, it will be seen that the position shown there would give but very little shake, for the reason that tooth C is in contact with tooth G, while B almost abuts with leaf E. The reason for the variation in the power delivered in this case is that when a tooth begins its action its point

of contact is nearer the center of the pinion than it should be, and as it continues its action the angle formed between the points of contact of tooth and leaf, as regards the line of centers, keeps constantly increasing until by the time they reach the point shown in Fig. 14 by tooth C upon leaf G, the force is excessive. This will be explained and graphically illustrated as we proceed to consider the effect of a shallow depthing.

Fig. 15 represents a wheel and pinion having the same center distance, and the pinion having the same diameter, as in Fig. 14. In Fig. 15, however, the wheel is one per cent smaller than it should be, thus making a shallow depthing. It will be noticed that the curve of the pinion leaf begins where it should—at the pitch circle—while the curve of the tooth face begins back of its pitch circle. Tooth A is some distance from its leaf E. Tooth B is in contact with its leaf F, although their flanks have not reached the line of centers. Tooth C has ceased its action on leaf G. This we call "beginning action before the line of centers." It will also be noticed in this depthing that instead of the face of the wheel tooth beginning its action upon the flank of the pinion leaf, as should be the case, the faces of the two act upon each other, practically during the entire time of contact, the effect of which is to increase the friction by driving the two pivots apart against the sides of their bearings. In the course of time a depthing of this kind will wear indentations at one side of each wheel tooth—where it comes in contact with the pinion. This is clearly shown at A, Fig. 16.

Just such worn places are sometimes seen on train wheel teeth, and are especially noticeable when they occur on the barrel. A shallow depth is even more likely to create a variation of power than a deep one. The reason for this is that when it begins its action it does so to a great disadvantage, owing to the angle formed above the line of centers by the wheel tooth and pinion leaf. This is illustrated in Fig. 17.

In this figure, A represents the center of a wheel—the driver; B, that of the pinion—the driven. The line AB is the line of centers. A1 and A3 represent the distances from the center of the wheel to the points of contact between tooth
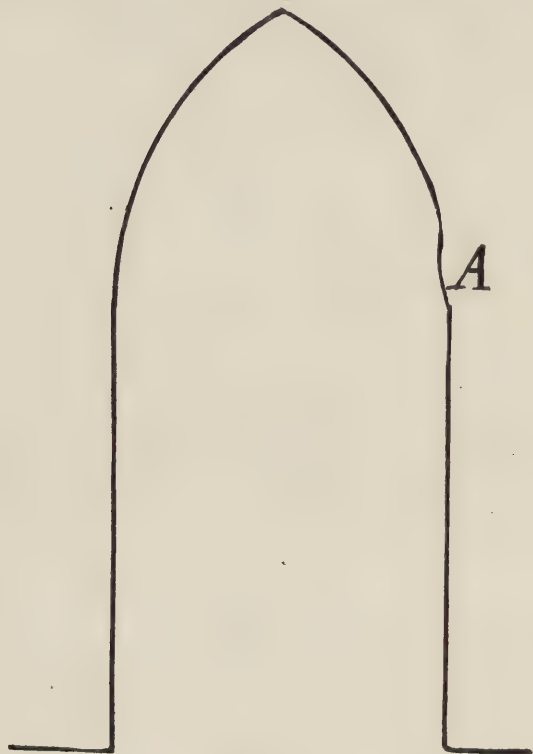

Fig. 16.

and leaf, 1 being the point of contact before, 3 the point of contact after, the line of centers. B1 and B3 show the distance from the center of the pinion to the point of contact of its leaves with the wheel teeth before and after the line of centers. The respective leverages of the wheel and pinion when the contact is at point 1 is determined by draw-

ing a line, 1, 2, at a right angle with A1, and where this line intersects the line of centers determines the respective value of the leverage, which is as A2 is to B2. When the point 3 has been reached the conditions are materially changed, and the leverage is now as A4 is to B4.

The teeth of wheels driving pinions of less than ten leaves are more difficult to form than those of ten or more leaves.

Fig. 18 is a wheel of 60 teeth driving a pinion of 6 leaves.
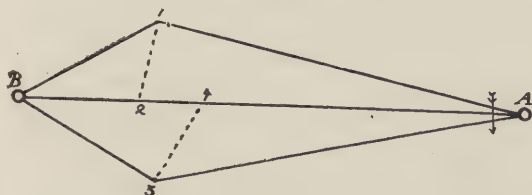

Fig. 17.

This is a proportion common to cylinder watches as well as all watches of less than 0 size.

A 6-leaf pinion makes, at best, an imperfect depthing; when carelessly designed or badly pitched, it is almost certain to make trouble.

We have said that the epicycloidal curve is not as well suited for watch gearing as a continuous circular arc of proper diameter. Fig. 18 demonstrates this. In this figure the faces of the wheel teeth are epicycloidal curves generated by a circle one-half the pitch diameter of the pinion. That curve is particularly unsuited to a tooth driving a pinion of 6. As shown in Fig. 18 a butting would occur when the action begins on a leaf; see tooth A and leaf B. It will be also noticed that the action begins a considerable distance before the line of centers is reached. The condition shown in Fig. 18 would probably stop the watch.

The wheel tooth for such gearing would have to be more full toward the point and somewhat longer, but as has been

said, a 6-leaf depthing is imperfect, even under the best conditions that it is possible to secure.

The addendum has been referred to as the distance that the points of teeth project beyond the pitch circle. There are at present several rules for calculating addenda, but unfor-
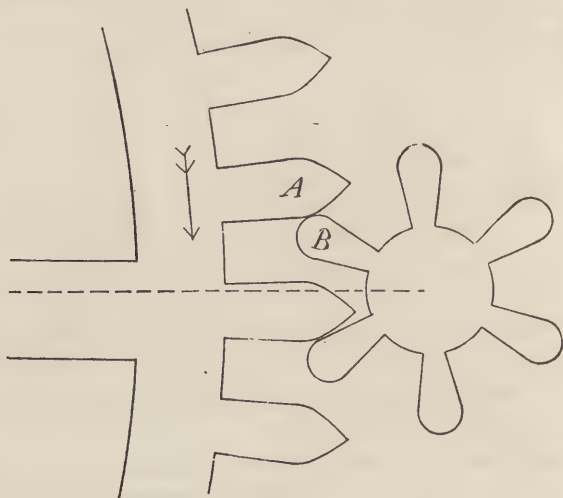

Fig. 18.

tunately these rules conflict with each other. This variance is probably due to the fact that the rules referred to do not take the pinion into account. They invariably calculate the addendum from the pitch diameter and number of teeth in the wheel, ignoring entirely the diameter or the number of leaves in the pinion.

Frodsham gives 2.5 of the pitch diameter for the addendum. That is to say, the pitch diameter is divided by the number of teeth and two and one-half of these divisions is the amount added to the pitch diameter for the diameter of the wheel over the points of its teeth. Arnold gives 2.25 for the addendum. Willis gives 3. These are all authorities on horology; but it is evident that all of them cannot be

correct. The fact is that the amount added for the faces of the teeth, where the wheels gear into pinions of small numbers, as in watch work, should be in proportion to the number of teeth in the wheel and the leaves in the pinion.

It is claimed by some authorities that a wheel of 70 to 80 teeth, gearing into a pinion of 8 leaves, cannot be made to begin its action at the line of centers, but must of necessity begin before it reaches that point.

The depthing about to be described illustrates a wheel of 80 teeth driving a pinion of 8 leaves, the leaves so formed that the action begins exactly at the line of centers.

The advantage of this has already been explained.

It is a well known fact that the epicycloid curve is not as applicable to watch gearing as a face formed by an arc of a circle, provided that arc is of such a radius that it will give a smooth action with the minimum of power. This is due to the fact that a great deal more play between the tooth and leaf must be left in watch gearing than in gearing for ordinary purposes.

A method will now be described whereby a curve, giving all the conditions necessary for a smooth depthing in watch trains, may be determined.

To make this method perfectly clear it is advised that the reader make a drawing as shown in Fig. 20. In making this drawing we will begin with a predetermined center distance, also numbers of teeth and leaves, making the drawing to exact scale. This scale should be very much enlarged on the drawing.

A diagonal scale, as shown in Fig. 19, will be found a great time saver in making drawings of this kind. It is very easily made. Bristol board or any other smooth faced drawing paper is suitable for the purpose. A sheet of transparent celluloid is also excellent when it can be obtained.

Referring to Fig. 19, the figures 0, 1, 2, at the top, to the right, indicate millimeters, expressed mm.; those 1 to 9 in-

clusive, running horizontally to the left of 0, indicate tenths
of millimeters; those 1 to 9 inclusive running downward, at
the left, indicate hundredths of millimeters.   The principle
involved in this scale is that the lines running downward,
at the left of 0, diverge from the perpendicular .1 mm., thus
allowing measurements to be taken accurately to .01 mm.
Thus, to take a measurement of 1.13 mm. place one divider
point at the intersection of line 1, at the left of 0, with
the line marked 3 and the other point at the intersection of
the same line (3) with the line 1 at the right of 0. The space

Fig. 19.

between the divider points will then be 1.13 mm. The scale
may be made for whatever enlargement is desired, thus
eliminating much calculation, as all measurements may be
taken directly from the scale.

Having prepared your paper for the sketch, let us assume
that the drawing is to be enlarged 50 diameters and that the
diagonal scale corresponds thereto.   The center distance is
to be 6 mm. long.   Draw line, A, 6 mm. in length, using
for this purpose your enlarged scale, which you have just
made.

As has been explained, the wheel is to have 80 teeth, the
pinion 8 leaves.   The primitive diameters of the members—
the diameters to the pitch circle, or pitch diameters—are in
exact proportion to the numbers of their teeth, which is as
1 to 10, therefore we divide the line of centers into 11 equal

parts. Taking 10 of these for the radius of the wheel, we lay off an arc of a circle, B, with the radius 10 elevenths of the line A. From the other end of line A we mark a circle, C, touching the arc, B, at the line of centers. The circles, B and C, are the pitch circles of the wheel and pinion.

In this case we have determined the diameters by making the radii as 1 to 10, but it frequently happens that the wheel is not a multiple of the pinion
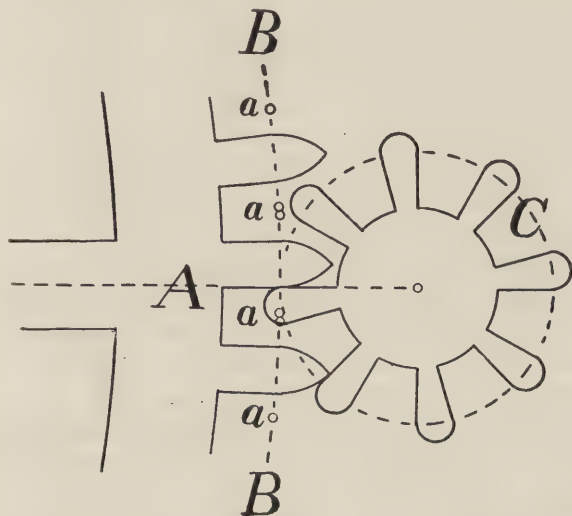
Fig. 20.

A rule for determining the pitch circles, under all conditions, is as follows:

For the radius of the wheel, multiply the center distance by the number of teeth and divide the product by the number of teeth and leaves added together.

For the pinion, multiply the center distance by the number of leaves and divide the product by the number of leaves and teeth added together.

The quotients being the radii, must each be multiplied by 2 for diameters.

Multiplying any diameter by 3.1416 gives the circumference.

The distance obtained by dividing the circumference by the number of teeth is called the circular pitch; that obtained by dividing the diameter by the number of teeth is the diametric pitch.

Thus, 6 mm. multiplied by 80 and the product divided by 88 gives 5.444 mm., which is the radius for the wheel. The difference between that and 6 mm. is, of course, the radius of the pinion. These radii multiplied by 2 give the diameters. Multiplying the wheel diameter, which is 10.888 by 3.1416 and dividing the product by 80, gives .428 mm., which is the circular pitch of the wheel.

In the present case, inasmuch as the wheel teeth are divisible by the pinion leaves without a remainder, most of this calculation can be dispensed with.

Again referring to Fig. 20, divide the circle C. beginning at the line of centers, into 8 equal parts. Each part will be the circular pitch, and inasmuch as the circular pitch of both wheel and pinion are alike, this distance may be transferred to arc B from the line of centers.

We have now to determine the thickness of the teeth and leaves. A very good proportion for watch gearing is nine-twentieths of the circular pitch for the thickness of the tooth, seven-twentieths for the thickness of the leaf. Lay out these respective distances on the pitch circles, B and C, and draw in the flanks of the wheel teeth and the pinion leaves, which are always radial lines.

The curves forming the faces of the teeth should be so shaped that when one tooth begins action on the line of centers, the tooth in advance of it, still in contact with a leaf, should be about to cease. Where pinions of small numbers are used, more than one tooth of the wheel is not in action for any length of time.

By the system here shown, the curve of the tooth is made from a center somewhere on the pitch circle. This point

is selected so that the curve shall contact near its point with
a pinion leaf, as shown. This point can be ascertained by
trial. In this case the radius of the curve is 69 per cent of
the circular pitch, which is .295 mm. The addendum in
this case is approximately 3 of the diametric pitch, which
agrees with Willis rule, but while it agrees in this particular
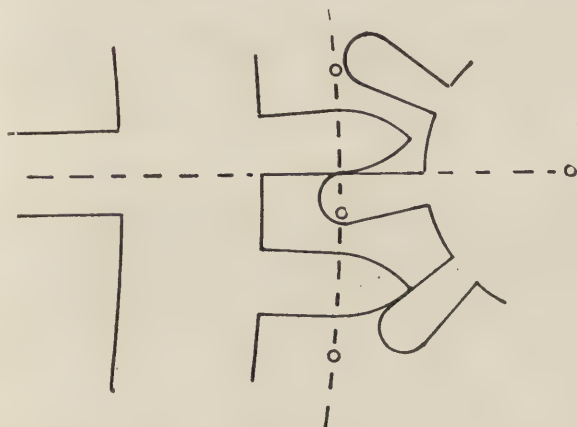depthing it would be found at variance in others.

Fig. 21.

Fig. 21 illustrates this. In this figure we have a wheel of
75 teeth gearing into a pinion of 10 leaves. It will be seen
that the curve of the face of the tooth is made from a pro-
portionally shorter radius than that used in Fig. 20. The
center from which it is developed is located exactly midway
between two wheel flanks. The result is that the addendum
is approximately two and one-half of the diametric pitch,
agreeing with Frodsham's rule. In a 14 leaved pinion, Arn-
old's rule—two and a quarter of the circular pitch—would
be about right.

In case the student desires to investigate this method, by
demonstration, he can readily do so as follows: Make a

drawing as illustrated in Fig. 20, but with the line of centers extended the full distance to the center of the wheel Placing tracing cloth over this drawing, first draw in the pinion. Then placing another piece over the wheel, draw that in. Now insert needles through the center of each and into drawing paper stretched on a board, being careful that these needles shall be at a distance apart, agreeing accurately with the line of centers. The tracing cloth may now be rotated on the needles, and being transparent, the action of the wheel teeth and pinion leaves can be readily seen. Made on a large scale, they will illustrate a depthing even better than the actual members in a watch.

How to Locate a Defective Depthing.—A defective depthing may stop a watch. When this is the case, the proper way to locate the trouble is to carefully lift out the balance and pallets. Then, beginning at the escape wheel, try the wheels one after another until it is found just where the power ceases. In case the defective depthing is not sufficiently serious to stop the watch, but is made manifest by the variation in the motion of the balance, it can generally be located by observing the intervals elapsing between successive fallings off of motion. When this manifests itself, the first step to take is to ascertain whether each wheel, individually, is free on its bearings. For this purpose try them separately. If they are all found to be free, it is fair to assume that the difficulty may be in the depthing, and if so the intervals will correspond with the consecutive passages of the pinion leaves with regard to the teeth that impel them.

If the difficulty lies in the barrel and center depthing, the intervals will amount to, usually, about 5 minutes. The exact time may be determined by dividing one hour by the number of leaves in the center pinion. It makes no difference whatever as to the number of teeth contained in the

barrel. Should the center have 12 leaves, dividing 60 minutes by 12 gives us 5, the intervals would be 5 minutes. Should the center have 14 leaves, dividing 60 minutes by 14 gives us an interval of 4 minutes, 17 seconds. For a center and third depth, divide the number of seconds in an hour—3,600—by the number of teeth in the center wheel, which will generally be 64, 72, 75 or 80.

For 64 teeth the intervals will be 56¼ seconds.

For 72 teeth the interval will be 50 seconds.

For 75 teeth the interval will be 48 seconds.

For 80 teeth the interval will be 45 seconds.

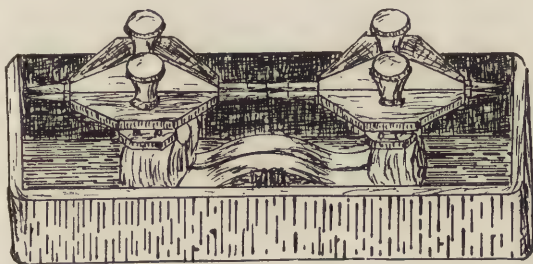For a third and fourth depthing, divide 60 seconds by

Fig. 22.

the number of leaves in the fourth pinion. This number will generally be eight or ten. If it has eight leaves the intervals will be 7½ seconds; if it has ten leaves, the intervals will be 6 seconds. The fourth and escape depthing is so near the end of the train that it is impossible to judge it by intervals.

THE DEPTHING TOOL.—This invaluable tool is shown in Fig. 22. It costs so little—about $2—that there is really no excuse for a watchmaker being without it. In using it to test a depthing, insert the points on the outer ends of the spindles into the pivot holes of the depthing to be tested. The lower plate of the watch is best suited for this purpose.

Lay it upon the bench, dial side down. Now, holding the depthing tool so that the spindles are perfectly perpendicular, adjust them carefully in the holes, the distance apart of which is to be measured. It is highly important that these spindle points should be absolutely central in the holes, as shown in Fig. 23, and that the spindles be perfectly upright; otherwise you will not have the correct distance to try your depthing. Having secured the correct distance, place the wheel and pinion to be tested, each between two of the spindles at the center, about midway between the heads of
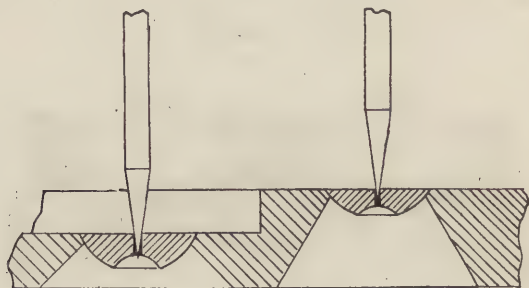

Fig. 23.

the depthing tool. The depth can then be examined and the nature of the difficulty can be determined as explained in connection with Figs. 14 and 15. Should it be desired to measure the center distance, it can readily be done by measuring across the outside of the spindles and deducting from the measurement thus obtained the diameter of one spindle. This, of course, will give the distance apart from center to center. The workman can then calculate the elements of the depthing as he would if he was laying it out originally and correct it accordingly.

TO REPLACE A MISSING WHEEL OR PINION.—This is a matter attended with some difficulty, for the reason that it is practically impossible to tell exactly where the pitch circle of a finished wheel is located. If the same method was

always used in determining the diameter over points it
would be an easy matter, but as we have seen, this is far
from being the case. The result of this is that when it is
desired to fit a wheel to gear into a certain pinion, or a
pinion to gear into a certain wheel, to replace a missing one
it becomes a matter more or less of conjecture. If the
workman familiarizes himself with the general principles
of gearing—and the best way to do this is by making draw-
ings—he will find his task much lightened.

One matter, in this connection, he can always determine
with accuracy the correct number of teeth or leaves. We
have said, "always determine;" this is not absolutely cor-
rect. Rare cases occur in the wheels at the end of a train
where the determination of the number may be attended
with some difficulty; for instance, when a barrel has an odd
number of teeth; but for the other members of the train
there is no difficulty to apprehend.

One revolution of a center wheel always revolves the
fourth pinion 60 times. Eight times seven and a half is
sixty, and this is the only practical way that the fourth can
be made to give its sixty revolutions.

The result of this is that the center wheel always revolves
the third pinion either eight or seven and a half times.
When it revolves it eight times the third wheel will revolve
the fourth pinion seven and one-half times, and vice versa.
This furnishes us with a ready means of determining the
numbers for trains.

Let us assume that a third wheel and pinion are missing;
that the center wheel has 80 teeth and the fourth pinion 8
leaves. It is necessary, in view of what has just been said,
that the pinion of the third wheel must have a number that
will go into the center either eight or seven and a half
times without a remainder. We find that 10 will divide 80
eight times without a remainder and that no whole number
can be found that will divide it seven and a half times with-

out a remainder; consequently the third pinion must have 10 leaves. For the number of teeth, in the third wheel it is only necessary to multiply the fourth pinion by seven and a half, which gives us 60 teeth for the third wheel.

Now let us assume that the fourth pinion, instead of having eight leaves, had 10, the conditions would be precisely the same with regard to the center wheel and third pinion. We should then simply have to give the third wheel 75 teeth.

Now let us assume that the fourth wheel and pinion are missing. In this case divide the center wheel teeth by the third pinion leaves. If the quotient is eight, divide the third wheel teeth by seven and a half for the number of leaves to give the fourth pinion. If the third pinion goes into the center seven and a half times, divide the third wheel teeth by eight for the fourth pinion.

We will now assume that the escape wheel and pinion are missing. We know that the escape wheel in a lever watch has 15 teeth; so it only remains for us to find the number of leaves in the pinion. Modern watches are either 18,000 or 16,000 trains. The 18,000 train gives 18,000 vibrations an hour—300 a minute. The 16,000 train gives 16,200 vibrations an hour—270 a minute. In the former case divide the fourth wheel teeth by 10 for the number of leaves in the escape pinion; in the latter case divide it by 9. If it is found that the fourth wheel cannot be divided by 10 without a remainder, it will be divisible by 9.

In case the center wheel and pinion should be missing, the method of determining the teeth in the wheel will at once suggest itself to the reader, for the reason that if the fourth pinion goes into the third wheel seven and a half times, the center wheel teeth will be eight times the number of the third pinion leaves, and if the fourth pinion goes into the third wheel eight times, the center wheel teeth will be seven and a half times the number of the third pinion leaves.

The number for the center pinion should not be very difficult to ascertain, inasmuch as center pinions invariably have 12 or 14 leaves. By simply measuring across two teeth in the barrel and working out the depthing from the center distances, as has been explained, it can quickly be determined whether the number for the center pinion is 12 or 14.

The most difficult part is to ascertain the proper number of teeth for the barrel, in case that member should be missing. But if the workman familiarizes himself with the method of calculating gearing, which has been fully explained, even this will present no serious difficulty.

To determine the correct numbers for missing parts in the dial wheel train, it should be remembered that there are but two combinations used to give 12 revolutions of the cannon pinion to one of the hour wheel. These combinations are simply 3 times 4, or twice 6, which is to say that the cannon pinion will either give 3 or 2 revolutions to 1 of the minute wheel, and that the minute wheel will either give 6 or 4 revolutions for 1 of the hour wheel.

Let us assume that the cannon pinion is missing; that the hour wheel has 40 teeth, the minute pinion 10 leaves and the minute wheel 36 teeth. In this case it would be seen that the minute wheel must revolve 4 times to carry the hour wheel around once, consequently the cannon pinion must revolve 3 times to carry the minute wheel once. The minute wheel having 36 teeth, the cannon pinion must have 12 leaves.

Let us assume that an hour wheel is lost; that the cannon pinion has 14 leaves, the minute wheel 28 teeth and the minute pinion 8 leaves. It follows that it requires 2 revolutions of the cannon pinion for 1 of the minute wheel, consequently the minute wheel must revolve 6 times for 1 revolution of the hour. The minute pinion having eight leaves, the hour wheel must have 6 times that number—48.

Now let us assume that the minute wheel and pinion are missing; that the cannon pinion has 11 leaves and the hour wheel 40 teeth. As the cannon pinion must revolve 12 times for 1 revolution of the fourth, we will multiply its leaves by 12, which gives us 132. We have seen that the cannon pinion must give either 2 or 3 revolutions for 1 of the minute wheel. Let us first try supposing it gives but 2. Dividing 132 by twice 11 (22) gives 6, but we find that the number of teeth in the hour wheel (40) is not divisible by 6 without a remainder, so this cannot be the correct number. Now dividing 132 by 3 times the leaves in the cannon pinion (33), we get 4, by which the number of teeth in the hour wheel is divisible without a remainder. This tells us that the minute wheel must revolve 4 times for 1 revolution of the hour wheel; thus we have ascertained that this combination is 3 times 4, 3 times the teeth in the cannon pinion (33) for the minute wheel and one-fourth the teeth in the hour wheel (10) for the minute pinion.

CHAPTER III.

It requires no argument to convince the watch maker of the advantage of jeweled bearings in a watch. They lessen the danger of abrasion, reduce the retarding effect of thickening oil and increase both the wearing quality and the time keeping efficiency to a very great extent.

Four kinds of precious stones are in use at present for watch parts. They are the diamond, sapphire, ruby and garnet. The diamond is used but very little, except for end stones for marine chronometers. The object of using it in this place is to prevent the end of the balance pivot from pitting—grinding a hollow in the face of the end stone. The balance of a marine chronometer is so heavy that its pivot would quickly pit a ruby or sapphire. For watch work, however, it is questionable whether a diamond is of any advantage. It is certainly no special advantage when one only of the balance jewels is capped with diamond. A marine chronometer is always run in one position, with the balance pivot running on the cock endstone, whereas a watch is comparatively rarely placed in that position.

The jewel next in hardness to the diamond is the sapphire. There is nothing better for balance jewels than the sapphire. It also makes a superior jewel for end stones, for impulse pins, in rollers, both lever and chronometer, for detent jewels in chronometers and duplexes and for pallet stones in levers, having steel escape wheels.

It is a curious fact that while sapphire and ruby pallet stones work better with steel escape wheels than garnet, they do not work well with brass escape wheels.

A sapphire or ruby is very apt to wear away the points of brass escape wheel teeth. This is very noticeable in the

duplex escapement, the staff of which is sometimes encircled with a ruby or sapphire jewel, and when this is the case the extreme points of the teeth cut away very fast. In the lever escapement a well polished and properly cornered garnet pallet stone seldom cuts the escape wheel tooth.

The ruby is a little softer than the sapphire, yet it is a hard stone, suitable for bearings for train wheel pivots. It is used chiefly in fine watches for this purpose. The highly colored ruby—pigeon blood—is much used for top plate jewels. Not that it is actually any better than the light colored, but simply for its beauty.
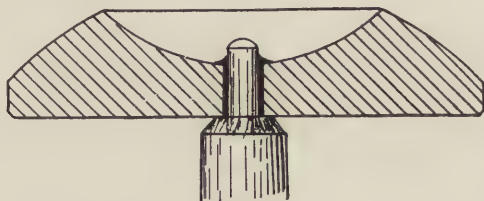
Fig. 24.

Garnets are much used for train jewels in medium priced watches and in the lower grades they are sometimes even used for balance jewels and end stones. While they answer fairly well for some of the train jewels, there are certain bearings that never should be made of garnet on account of its soft texture and its friability. It should never be used for center jewels, for balance jewels, nor for end stones.

In so small a piece as a watch jewel it is sometimes difficult to distinguish between ruby and garnet; but when the jewels are held side by side over a piece of white paper it will be noticed that the colors are quite different. The ordinary ruby is lighter in color than the garnet. Even the pigeon blood is rather lighter in color, but is of a very different shade from the garnet, the ruby being of the blood-red, while the garnet is of a claret wine color.

There are two shapes for the holes in jewels, the straight-hole and the olive hole. The straight-holed jewel shown in

Fig. 24 is suitable for train pivots, especially in centers and thirds. When used in fourths, escapes and for pallet arbors, the holes should be much shorter; that is, the thickness from the cup to the face should be less. The reason for this is that oil has a tendency to thicken with age when applied to a watch. This causes a resistance by adhesion, which retards the motion by offering resistance to the pivots at the end of the train—the escape.
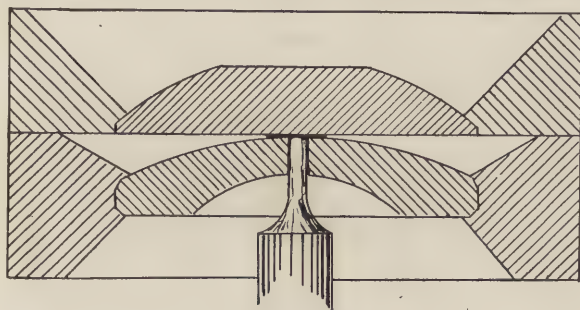
The question is often asked: "What advantage is there

Fig. 25.

in jeweling the escape wheel and pallet on the ends?" Herein lies the answer to that question:

The escape wheel, being the last revolving member of the train and revolving as it does 3,900 times to each revolution of the barrel, performs its work under a very much reduced power, with the result that as much resistance as possible should be removed where close time is required.

It is a well known fact that the greatest economy of power, so far as the bearings of pivots is concerned, is accomplished by using an olive hole jewel with an end stone above it. A square shouldered pivot, as shown in Fig. 24, increases the friction very much. A straight-hole, as shown in Fig. 25, is not so favorable as the olive hole shown in Fig. 26. By comparing the two figures it will be seen that the bearing in Fig. 25 being parallel to the pivot, produces a

much greater surface in contact than does the olive hole. Its disadvantage, however, is not that the friction is increased by the longer bearing—friction is independent of extent of surface—but that the adhesion caused by thick oil is increased. If we could run our watches without oil we would not require such powerful mainsprings. Even when the oil is first applied it exercises a retarding influence, and this retardation increases as the oil thickens with age and the addition of foreign matter.
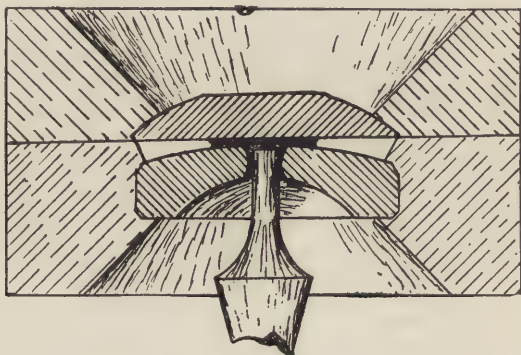

Fig. 26.

A peculiarity of retardation by thick oil is that the thinner the film the greater the resistance. Now the balance pivot is fitted with less side-shake than any other pivot in the watch; consequently there is a thinner film interposed between the pivot and the jewel. It will be readily seen therefore by reference to Fig. 26 that the olive hole reduces this excessively thin film to an extremely small portion of the length of the pivot, while in the straight-hole, as shown in Fig. 25, the thin film extends the entire length of the jewel hole.

FITTING AND REPAIRING JEWELS.—It is not the purpose to describe the process of manufacturing jewels. It is ex-

tremely rarely that a watch maker is called upon to do this. To those who may be interested in this branch we would recommend a work published by Hazlitt & Walker, of Chicago, entitled: "Jeweled Bearings for Watches."

It may sometimes be found desirable to enlarge and to polish a jewel hole. Simple instructions will now be given for doing this work:

For enlarging a jewel hole use soft steel wire. File it to a long, slight taper. Charge it with No. 3 diamond powder. It can be best charged by rolling the powder in, though it may be done by hammering.

In opening the hole keep the wire well moistened with soap. This will be found much quicker than oil for opening.

Having opened it to the proper size, polish it with No. 4 or 5 diamond powder applied loosely on finely tapered peg-wood, or tortoise shell.

It requires a high speed to polish a jewel hole. If a lathe running in one direction and the spindle carrying the polisher in the opposite is used, 1,200 revolutions per minute of each spindle will answer; but if the lathe only revolves, the polisher being held in the hand, the speed should not be less than 2,000. In case the corner, where the hole meets the face, becomes slightly chipped, it can be repaired by cornering. For this purpose use a copper wire, pointed at an angle of 45 degrees and No. 4 diamond powder.

SETTING A JEWEL.—The setting of a jewel is an operation the importance of which is not fully appreciated. Always have the jewel fit closely in the recess made to receive it. If the jewel itself is true with the hole, the bottom of the recess properly shaped and the setting edge of the jewel is of the same thickness all round, it will be perfectly true with the setting and its face will be flat when the setting burnisher is properly applied. Jewels are often set by simply drawing a slight burr over the face. Such a setting is not secure and is likely to cause trouble. To set a jewel properly the

burnisher should be thrust, point first, into the setting, throwing a strong wall against the setting edge, as shown in Fig. 27. A jewel thus set will never come loose, and the setting can be flushed off down to the face of the jewel.

In selecting a jewel see that it is free from flaws and air holes; that the face is well polished; also the hole; that the hole is slightly cornered and free from chips. Let the setting edge be slightly beveled, as shown in Fig. 27.
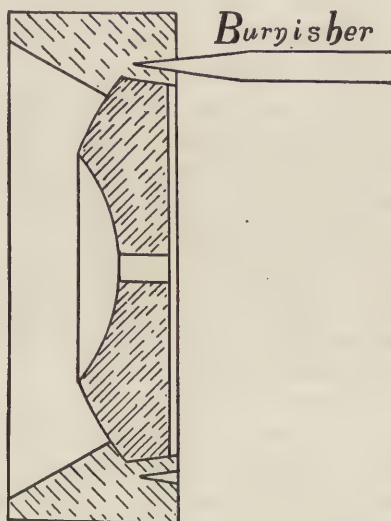

Fig. 27.

Where a jewel has been set directly into a plate it will generally be found best to replace it, when required, by a jewel placed in a setting, with the setting burnished into the plate. It is rarely that a really good piece of work can be done by resetting a new jewel into the bezel that held the old one.

It is of the utmost importance that the jewel and end stone be held the proper distance apart. If the jewels are not properly shaped and correctly located they will not re-

tain oil for any length of time. The oil is held about the
pivot by capillary attraction. The square shouldered pivot
retains it between the shoulder and the face of the jewel,
also between the pivot and hole and between the pivot and
oil cup. See Fig. 24.

When an end stone is used, provision is made for an oil
space between the top of the hole jewel and the face of the
end stone. This space should be from one to two hun-
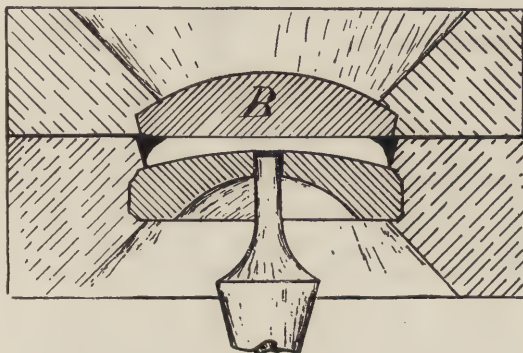dredths of a millimeter. With this space and a balance jewel

Fig. 28.

with convex top the oil will be held by capillary attraction
about the end of the balance pivot, as shown in Fig. 26.

Where the jewel and end stone are too great a distance
apart, as in Fig. 28, the oil will be drawn away to the sides
of the setting. The cause of this is that a liquid placed
between adjacent surfaces will seek the smallest space,
which in Fig. 28 is between the jewel settings, whereas in
Fig. 26 the narrow space directly over the jewel hole will
retain oil until the last atom is exhausted.

Fig. 29 shows the effect of placing an end stone directly
against the jewel hole. In this case the oil will gradually

find its way down the cone of the pivot. Inasmuch as it cannot get between the jewel and end stone, it will quickly dry out.
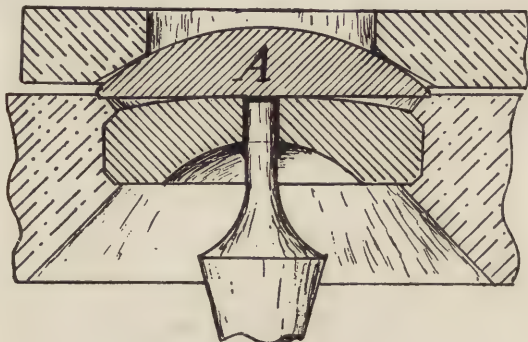

Fig. 29.

Another point to be observed, in setting a jewel or end stone—particularly the latter—is that they shall be parallel.

Fig. 30 represents an end stone set "out of flat." When the watch is turned with the pivot resting on an end stone
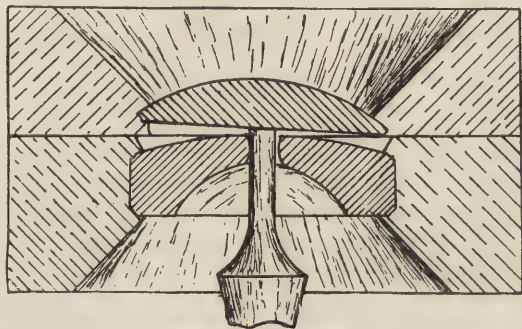

Fig. 30.

in this condition, it forces the pivot against the side of the jewel with increased pressure in proportion to the angle the jewel face makes with the pivot. It would be impossible to secure close position adjustment with an end stone so set.

CHAPTER IV.

Escapements—The Detached Lever.—There is no part of a watch that involves so many complications, or requires such an amount of study and practice as the escapement. There is no part of its mechanism about which more has been written, yet half has not been told.

To make a drawing capable of demonstrating the action of an escapement in all positions of its functions.

In laying out an escapement it is often required and is always desirable to know exactly how it will appear in various positions of its acting parts during the delivery of its impulse, while the fork is vibrating from banking to banking, the balance making its excursions and the escape wheel performing its intermittent arcs of rotation.

The usual method is to make several drawings showing the escapement, or parts thereof, in the desired positions. This requires time and patience and is ofttimes not entirely satisfactory, owing to the possibility of errors in delineation as well as the fact that although a multiplicity of drawings be made, still the escapement is not shown in *all* positions; a condition practically impossible when separate drawings are used.

The method here described and illustrated will produce drawings that may be used to demonstrate the action of an escapement with all the accuracy of a working model.

First make a drawing as in Fig. 31. This drawing may be made to show the escapement in any part of its action. In this case a wheel tooth is locked on the discharging stone. This drawing need not necessarily be inked in. Penciling will show through tracing cloth, answering the purpose for which the drawing is intended.

Take a piece of tracing cloth, as shown by the square bordered by dotted lines. Fasten it over the rollers, as shown in Fig. 32 and draw it in ink, embracing the impulse roller, its jewel and the safety roller.

Proceed in a similar manner with the fork and pallets, as shown by bordered dash lines. Draw in the escape wheel as shown bordered by dash-and-dot lines. The purpose of the arc above the escape teeth is to permit the wheel to be rotated, as will become apparent later on.

We now have the three members of the escapement—the rollers, the fork and pallets, the escape wheel—on separate pieces of tracing cloth.

Lay the original drawing on a piece of clean drawing paper, and with a fine needle prick through the original drawing at the centers of the roller, fork and pallets, and escape wheel. Remove the drawing, which will of course leave the three centers on the drawing paper. To avoid mistakes it is well to encircle these three points with pencil or ink.

Take three needles; attach suitable knobs to the eye end —shellac will answer. Insert these needles into the centers —one in each—of the three members drawn on the tracing cloth; place them in their proper relation by inserting the needle points into the drawing paper at the centers previously marked as described.

We now have an excellent substitute for a working model, whereby the members can be moved to any relative positions with each other, the action of the escapement being thereby clearly demonstrated.

Fig. 33 shows these parts after having been moved on their respective centers to a point where an escape tooth is delivering impulse to the discharging stone and is half way down its impulse face. The jewel-pin is now embraced by the fork slot.

The relative positions of the dot, the dash, and the dot and dash lines show clearly how the different tracings have
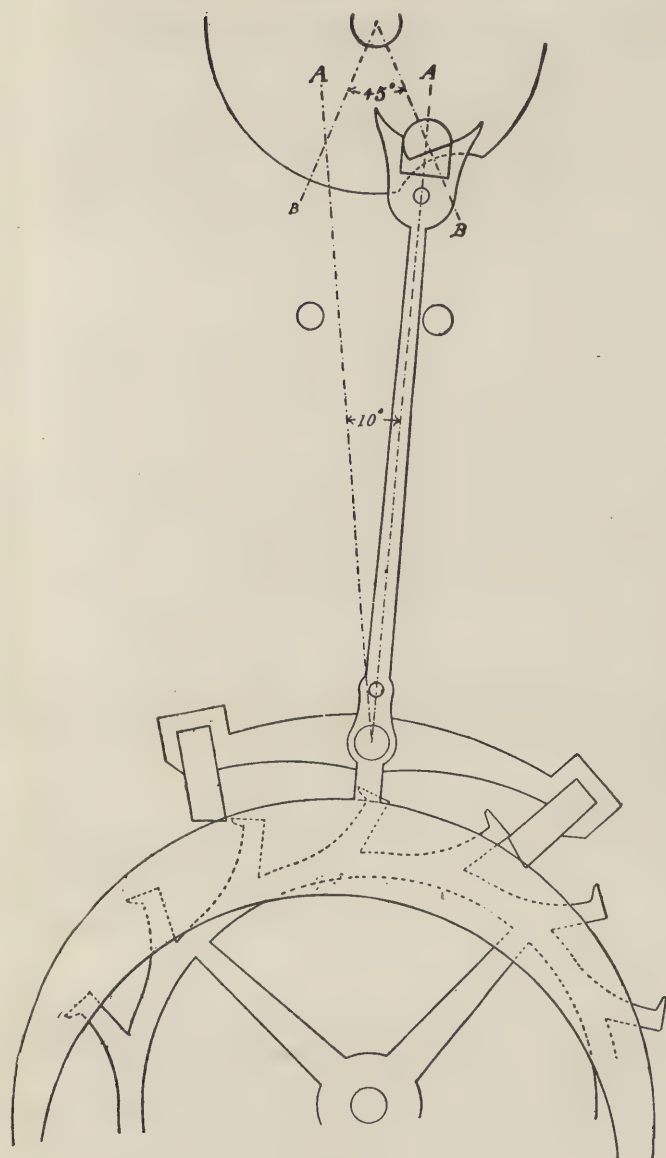
Fig. 31.

been moved to produce the results shown in Fig. 33. The ink lines offer no obstruction to the vision, showing clearly through the tracing cloth.

In order to adjust an escapement intelligently, a thorough knowledge of the nature of all its functions is essential. Theory and practice are both required. Theory alone will not make a good workman; practice without theory may do so, after a fashion; the two united make the rapid and skillful workman.

The escapement is complex in its character. The various individual functions are so intimately related to each other that no single one can be altered without affecting others to a greater or lesser degree. The consequence is that a workman will often make an alteration to correct an error, and in doing so will create another error, or aggravate a previously existing one. Without a good theoretical knowledge, hours may be spent over an escapement that, with a sound theoretical knowledge, might have been made right in minutes.

It has been the study of the author to present the theory in plain language, accompanying it with a multiplicity of illustrations, so that the most intricate problems involved may be clear.

The effects produced by the different alterations that may be made will be fully described and illustrated, thus directing the practice of the workman, so that nothing may be done at haphazard; that every operation performed will be for definite results; results that may confidently be expected.

NAMES OF PARTS.—The term escapement is applied to that part of the watch by means of which the rotary motion of the wheels is transformed into the vibratory motion of the balance. The members included in the escapement are: The escape wheel, the pallets, the fork, the impulse pin,
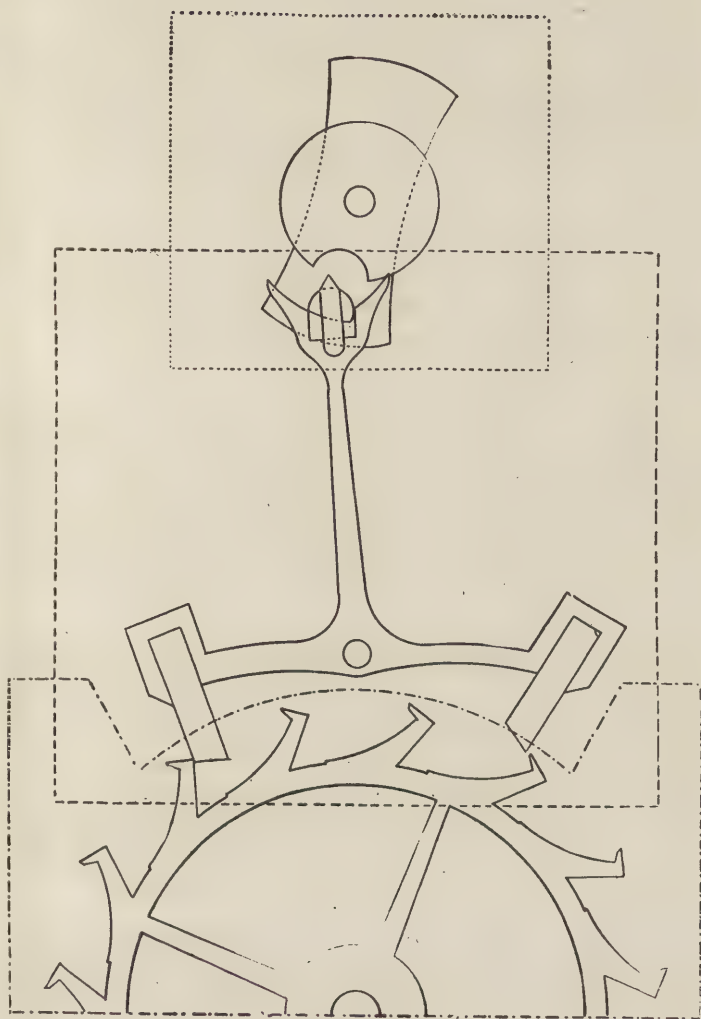
Fig. 32.

and the roller or rollers; the balance is not properly a part
of the escapement.

Inasmuch as more than one term is frequently used to
designate the same part, it is deemed well to give the differ-
ent names in general use.

In Fig. 34 the letters refer to the following list:

A, the escape wheel—scape wheel.

B, the pallets.

C, the fork.

D, the impulse roller—table roller.

E, the safety roller—guard roller—banking roller.

F, the impulse pin—roller pin—jewel pin.

G, the guard pin—safety pin—dart.

H H, the banking pins—bankings.

I, the receiving stone—R stone—right stone—straight
stone, entering stone.

J, the discharging stone—L stone—left stone—hook
stone—leaving stone.

K, the passing hollow—roller hollow—roller crescent.

L L, the fork horns.

COMPARISON BETWEEN THE SINGLE ROLLER AND THE
DOUBLE ROLLER ESCAPEMENTS.—The difference between
the single and the double roller escapement is entirely in
the safety action; the escape and pallet action and the fork
and impulse action may be identical in both forms.

The guard pin and the safety roller are provided for the
sole purpose of preventing what is commonly called "over-
banking"; more properly speaking, going out of action.

Referring to Fig. 34 it will be seen that the fork is to the
left, and that the roller is making its excursion in the direc-
tion indicated by the arrow, P.   The impulse pin is in the
act of unlocking the escapement; in this position the fork
cannot go out of action, being held in place by the impulse
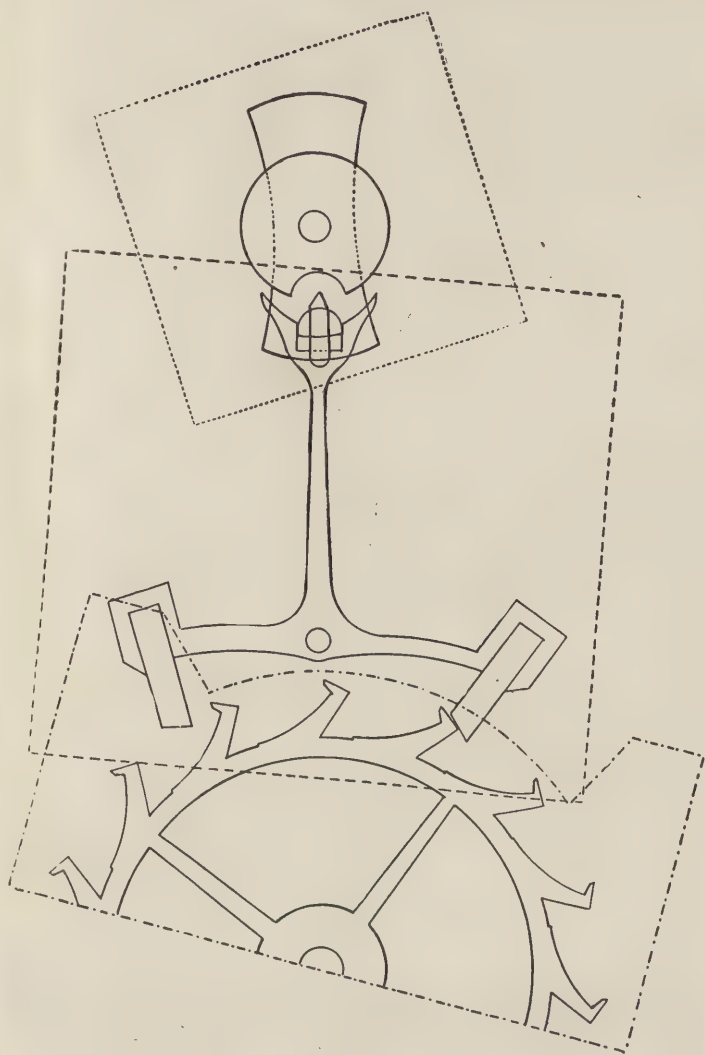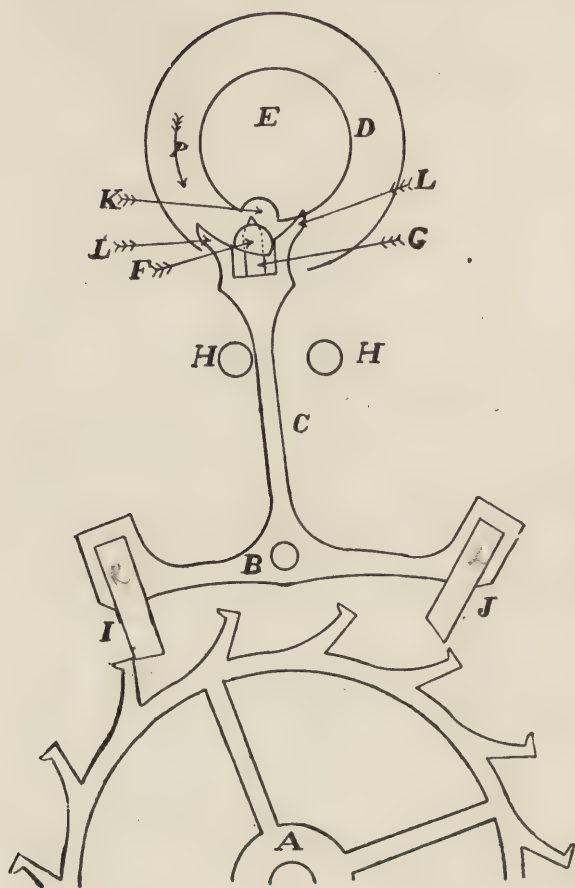pin.   When the impulse pin is out of reach of the fork horn,

Fig. 33.

Fig. 34.

the fork is kept in position by the safety roller; it cannot
pass the safety roller until the passing hollow comes into
position to allow it.

Fig. 35 illustrates the latter condition. This figure shows
the fork at the left, as in Fig. 34, but the impulse pin is

farther to the left, and out of reach of the fork horn. The fork is now prevented from over-banking by the edge of the safety roller projecting beyond the path of the guard pin. It is not deemed necessary to letter the parts in this drawing.

Fig. 36 shows a single roller under the same conditions as the double roller in Fig. 34; M is the roller, N the passing hollow, O the guard pin. The roller, M, performs the offices of both rollers, D and E in Fig. 34. In the double
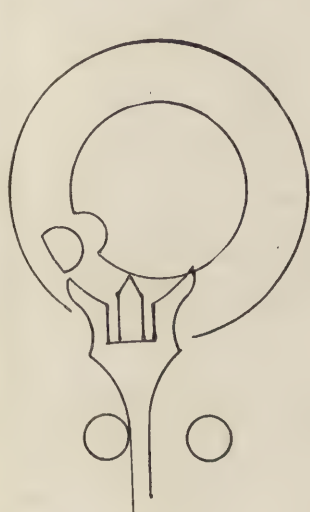
Fig. 35.
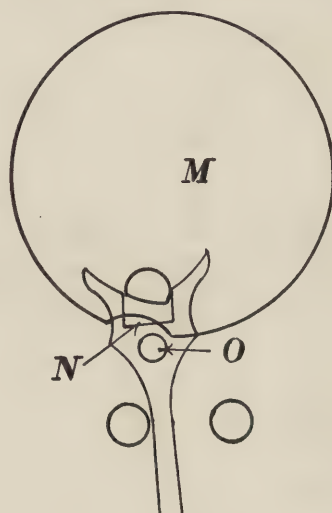
Fig. 36.

roller, the guard pin projects forward, under and beyond the impulse pin; in the single roller it stands perpendicularly with the fork and is back of the fork slot. The roller, M, not only carries the impulse pin, but its edge in conjunction with the guard pin provides the safety action.

ADVANTAGES CLAIMED FOR EACH FORM OF SAFETY ACTION.—There is a difference of opinion as to the respective merits of the two forms of escapement. It is not my

purpose to enter into this controversy; instead, the advantages and disadvantages of each will be set forth.

Fig. 37 shows a portion of an escapement with both forms in combination. The guard pin A is for the single roller action; the guard pin B is for the double roller action; C is
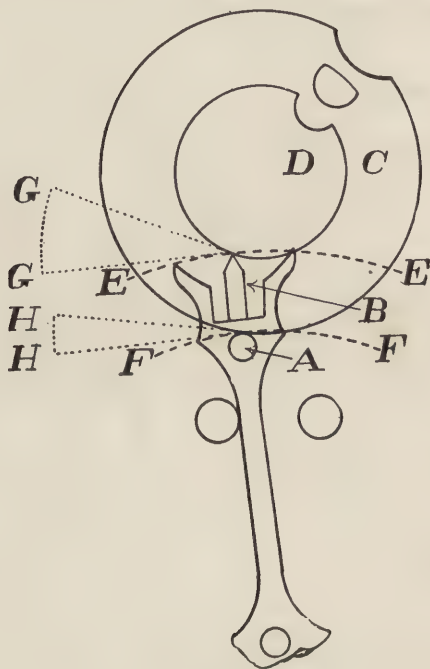

Fig. 37.

the impulse roller in the double roller form; D is the safety roller in the double roller form; C takes the place of both rollers in the single roller escapement.

The fork is shown against the left banking pin. The broken line, E E, is the path of the double roller guard pin;

the broken line, F F, is that of the single roller guard pin. It will be seen that the line, E E, penetrates beyond the periphery of the safety roller to a much greater extent than the line, F F, penetrates beyond the periphery of the roller C. The dotted lines, G G, are drawn tangent to the circumference of the safety roller and to the path of the guard pin, at their point of contact, in the double roller escapement; the dotted lines, H H, are in the same relation in the single roller escapement. These lines embrace the angles at which the respective guard pins contact with their rollers. It will be observed that the angle embraced by the lines, G G, is more than twice that embraced by the line, H H. It is, therefore, justly claimed for the double roller that it is much less liable to allow the escapement to over-bank than the single roller. It is also claimed for it, justly, that in case the fork is thrown against the roller edge, less resistance is offered to the motion of the balance, owing, both to the respective sizes of the rollers and the difference in the angles at which they contact, as shown by the lines, G G, and H H.

The points of advantage claimed for the single roller are: Less cost to manufacture; more simple in structure; that it can be made lighter; that there is a greater extent of safety action on the roller edge and less on the fork horns. The two latter points will become more clear as we proceed with the subject.

Loss of Power.—Before proceeding to consider this important part of our subject, it is well to give the terms used to designate the acting parts of the pallet stones and the escape teeth.

Fig. 38 in connection with the following list, makes this matter clear.

The parts of the stone are: A, the locking face; B, the impulse face; C, the locking corner; D, the releasing corner.

The parts of the wheel tooth are: E, the locking face; F, the impulse face; G, the locking corner; H, the releasing corner.

There is a great loss of power inseparable from the lever escapement even under the most favorable conditions.
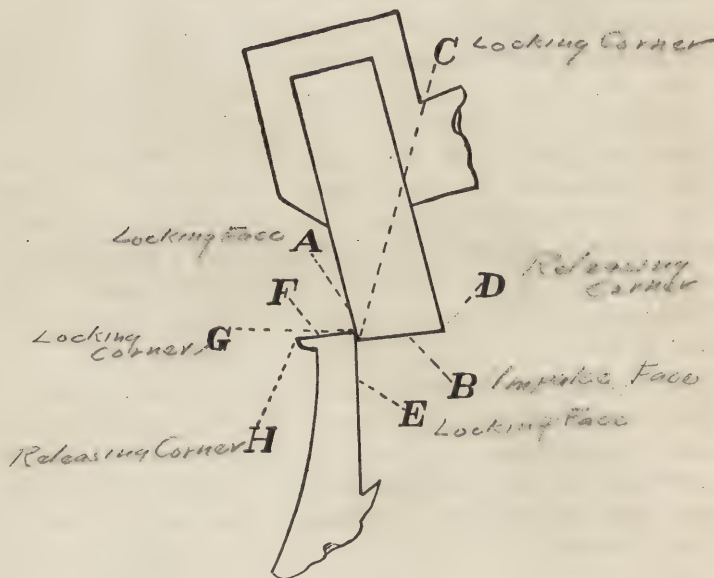

Fig. 38.

There is more loss of power entailed in conveying the motion from the escape to the balance than in all other losses of power combined. Of the force conveyed from the mainspring, through the train, up to the escape wheel teeth, *upwards of one-third* is lost before it reaches the balance.

This will no doubt seem a surprising, mayhap, an incredible statement; it will be fully proved by Fig. 39 and the specifications connected therewith.

In order to avoid confusion, the members constituting the safety action have been omitted in this figure; those members have nothing to do with the conveyance of power.

The escape wheel has 15 teeth; the quotient of 360 degrees divided by 15 is 24 degrees; therefore the angular distance between similar points of adjacent teeth is 24 degrees, as shown by lines A. A. One revolution of the escape wheel causes each tooth to deliver two impulses to the pallets—thirty impulses in all; one impulse on the receiving stone, one on the discharging stone. This gives 12 degrees of angular motion for each impulse. The entire 12 degrees, however, cannot be used for impulse; a certain amount is necessary for freedom; this is called the drop. In the drawing, tooth B has just been released from the discharging stone and tooth C arrested by the receiving stone. The angular distance between the releasing corners of the discharging stone and tooth B is the amount of the drop; the drop is just that much lost power. The wheel passes through that portion of each revolution without doing any effective work, its force being lost in the impact when it is stopped by the pallet. The amount of drop is usually 2 degrees, as shown by the lines D D. This involves a loss of 16⅔ per cent, exclusive of that in the impact.

The arc of impulse of the fork, from banking to banking, in Fig. 39, is 9½ degrees, as shown by lines F F. In the drawing, E E is the line of centers; the lines, F F, include the arc of vibration. Of this 9½ degrees of vibration, ¾ of a degree must be deducted for lock, as shown by lines G G, which pass through the locking corners of tooth C and the receiving stone. This leaves 8¾ degrees for actual impulse; a loss of more than 7 per cent; and bear in mind that this 7 per cent loss is 7 per cent of the power left after deducting the loss from drop.
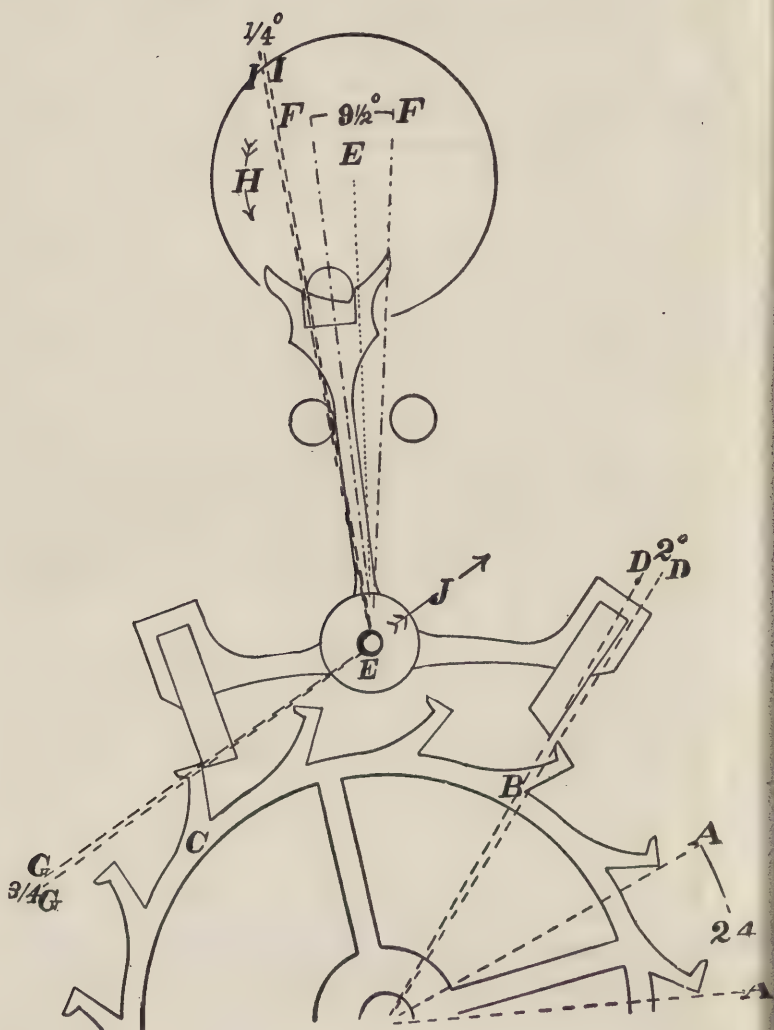
Fig. 39.

The impulse pin must be allowed some freedom in the fork slot. This, which is called roller pin shake, will be understood by referring to the drawing, which shows the fork held against the left banking, the tooth locked on the receiving stone. Let us assume that the roller is making an excursion in the direction indicated by the arrow, H. In making this excursion, the impulse pin enters the fork slot, and, coming in contact with its right side, moves the fork to the right, thereby unlocking the wheel tooth. When the tooth passes to the impulse face of the stone the fork immediately moves to the right until the left side of the slot contacts with the impulse pin; this is called roller pin shake. Its amount is usually $\frac{1}{4}$ degree, as shown by lines II. A loss is thus incurred of 3 per cent. The losses thus far given bring the aggregate up to about 27 per cent, for we must bear in mind that each deduction for loss is the given percentage of the amount remaining after the previous deduction. There remain other losses, the exact amount of which cannot be readily calculated, such as friction, impact and side shake. Perhaps the side shake in the pallet arbor jewels is the most serious of these.

As the various impulses are applied and the resistance encountered by the members of the escapement, their pivots are forced against their bearings in different directions. This may readily be detected through a double eye-glass by looking directly down on the pallet arbor pivot while the balance is in motion; the side shake will show more plainly when the jewel and pivot are clean and unoiled. When the parts are in contact under the conditions shown in Fig. 39 the pallet arbor is pressed against the side of the jewel hole in the direction indicated by the arrow J. As the impulses are delivered alternately to the stones, and the resistance of the impulse pin is encountered, the pivot will be seen to rock from side to side in the jewel, thus incurring a loss of power; hence *it is important that the side shake in these*

jewels should be as close as possible, consistent with proper freedom.

It is well, just at this place to call attention to the difference between straight line and right angle escapements. The former is almost universally used at the present time. The English form, which is still used by them to some extent, is the right angle escapement. So far as loss of power by side shake of the pallet arbor pivots is concerned, the right angle escapement has the advantage, for the reason that the rocking of the pivots does not prevail to nearly so great an extent as in the straight line. The fact that in the English ¾ plate the upper escape jewel, as well as the pallet jewel was placed under the balance, thus making the escape pinion quite short, may have had much to do with the adoption of the straight line escapement.

Another loss of power to which attention is called is the result of the impacts of the escape teeth with the pallet stones, and the impulse pin with the fork. To fully appreciate this, the fact must be kept in mind that the fork is started up from a dead rest at each vibration and that it comes to a sudden stop at the end of each vibration.

It is a well known law of force that when two bodies (one or both being in motion) come in contact, force is transformed into heat in proportion to the velocities and masses of the bodies. When the impulse pin comes in contact with the fork the balance is at its maximum velocity; the impact is therefore great in proportion to the weight of the parts involved. A homely illustration will serve to illustrate this: One can easily push a brick across a table with the little finger; if he drives it across with a blow of the fist, he will realize something of the difference between force applied gradually, and that applied violently; in other words, between force and impact.

Another condition existing in the fork and roller action is that the movement of the fork is practically uniform,

while that of the balance varies. A balance having a motion
of a turn must necessarily travel at a higher rate of speed
than if the vibration were half a turn. When the impulse
pin is in contact with the fork the balance is at its maximum
velocity; as the pin first contacts with the fork it releases
the escape wheel by unlocking; immediately thereupon, the
resistance of the fork is reversed; it begins to exercise force
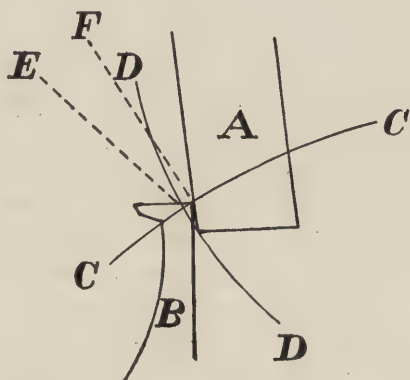to accelerate the motion of the balance, but the balance being

Fig. 40.

at a higher rate of speed has a tendency to recede from its
pressure—to get away from it so to speak; the consequence
is that as the motion of the balance increases the efficiency
of the force of the fork decreases. This is why putting a
balance out of beat increases its arc of vibration and
changes the rate of the watch; by the way, it is a trick
sometimes resorted to by adjusters; needless to say, a rep-
rehensible one.

It will be seen from the foregoing that placing the loss
of power at one-third is a very conservative estimate.

The recoil in unlocking is a source of error that sometimes makes itself felt in adjustment.

Fig. 40 illustrates what is meant. The drawing is made to exaggerate the condition for the purpose of making the point clear.

A is a pallet stone, B an escape wheel tooth. The circular line, C C, is the path of the locking corner of the tooth. The circular line D D is the path of the locking corner of the stone. In unlocking, the stone passes along the arc D D and the tooth along the arc C C; the unlocking takes place at E, where the lines C C and D D intersect. It follows then that the tooth must be forced backwards from the point F, where it is shown on the drawing, to the point E, where it unlocks. This is the recoil. In forcing the escape wheel backwards, the fourth, third, center, and barrel are all in their turn reversed; this actually winds up the mainspring 300 times a minute. True, it is an infinitesimal amount, but let it be understood that the entire impulse delivered by the escape wheel is but a minute fraction of the rotation of the barrel. Where the center pinion has 11 leaves and the barrel 80 teeth, the power is reduced 15,875 times.

THE FORK AND ROLLER ACTION.—An improperly fitted, or wrongly located, impulse pin is perhaps the most common error found in escapements.

A roller pin should have 1½ to 2 hundredths of a millimeter shake in the fork slot. It may not be convenient to measure this shake, nor will it be necessary; it can be judged by sight or by touch.

Those who have access to a metric gauge can readily determine how that amount appears to the eye; those who have not, can judge by comparison.

Dennison's tissue paper for watch-makers' use measures in thickness about 4/100 of a millimeter. One-third of this will give the right amount of shake. By fitting a pin of any material so that a scrap of tissue paper will take up the shake, the eye can be accustomed to recognize the proper amount, which should be one-third of that.
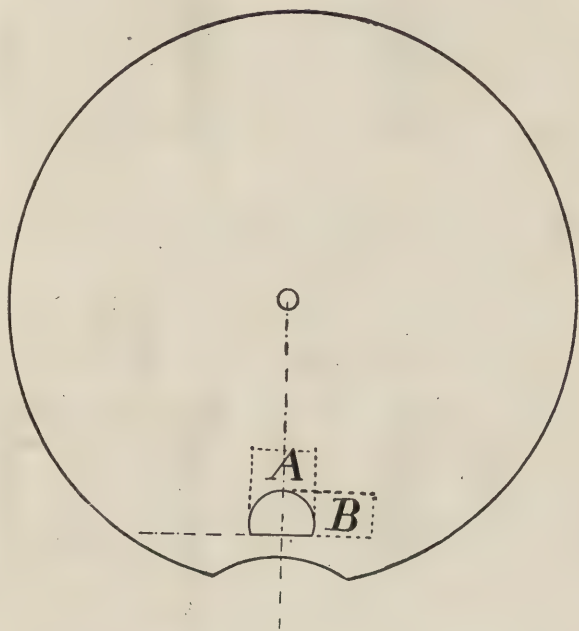

Fig. 41.

The roller pin should be set firmly in the roller. It should be perfectly upright, neither leaning forward, backward, nor sidewise. If it is a flat-faced pin, its face should be square to the front; that is, at right angles with a radial line from the center of the roller, as shown in the broken lines in Fig. 41.

A D-shaped impulse pin should be flattened to about two-thirds of its diameter; the diameter B should be two-thirds that of A. If the pin is of oval form the widest portion—major axis—should be at right angles with the radial
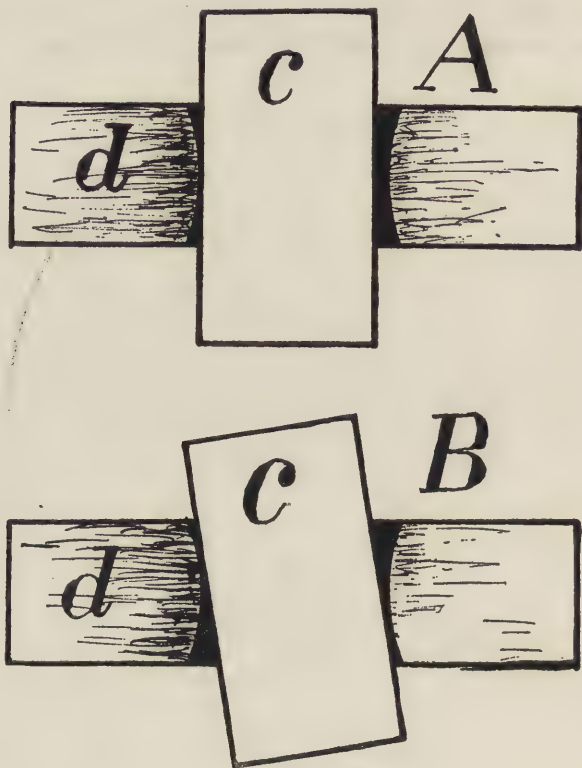
Fig. 42.

line; if a round pin, simply set it upright. Here let it be understood that the two latter forms are only used on low grade watches; an escapement can not be closely adjusted with a round or an oval pin. Triangular pins are used to a limited extent; these should be set in the same manner as the flattened cylindrical pins.

Fig. 42 shows the effect of a jewel pin tilted sidewise. In this figure A shows a pin set upright; B a pin set out of upright.

Referring to A, it will be seen that the pin, c, has a certain amount of side shake, as indicated by the black portion at the right of the pin; referring to B, the pin, c, being tilted, takes up all the side shake.
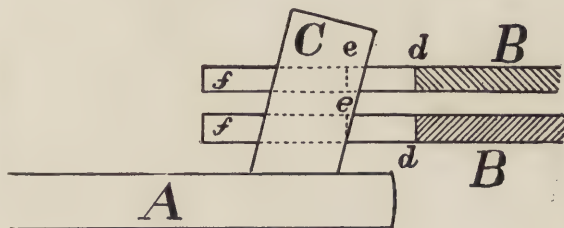
Fig. 43.

Fig. 43 shows the effect of tilting a pin forward. In this figure A is a roller, B a fork, C a jewel pin. Where the section lining ceases, at the lines d d, is the bottom of the fork slot. The perpendicular dotted lines e e represent the front end of the slot, where the curve of the horn f begins; the fork is shown in two relative positions to the jewel pin. It is evident that owing to the necessary end shakes of the balance and fork, the fork will vary with regard to longitudinal position on the roller pin. In the uppermost position, the jewel pin penetrates a greater distance into the fork slot than in the lower; this variation (being liable to constant change) is detrimental to regularity of rate; its effect on escapement adjustment will be more fully explained as we proceed.

Fig. 44 shows the proper position for the jewel pin when entering or leaving the fork slot. The bankings are set correctly for lock and slide; the escape wheel and pallet are not shown. It will be observed that the face of the jewel
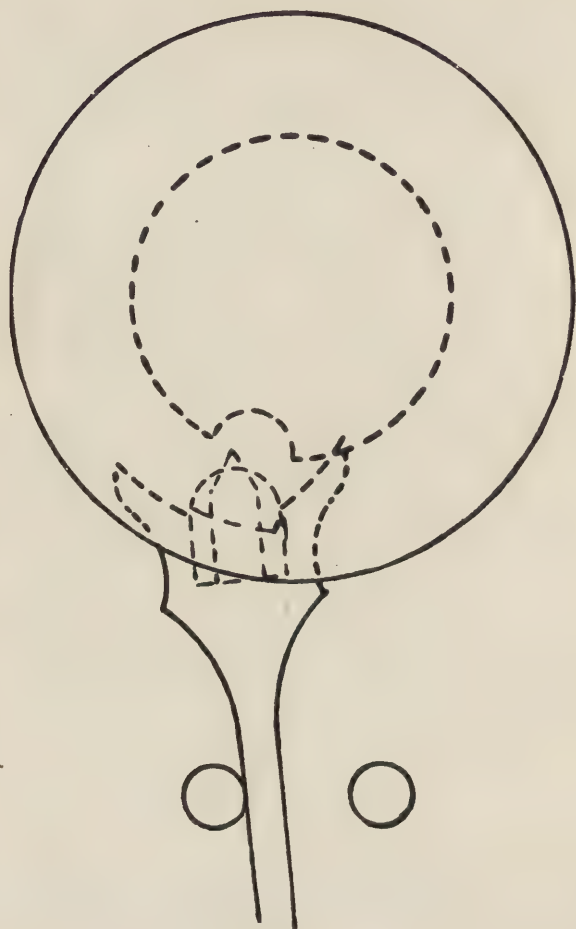
Fig. 44.

pin clears the curve of the fork horn. The fork is against the left banking, but if at this instant it should be moved to the right, the left corner of the slot would come in con-
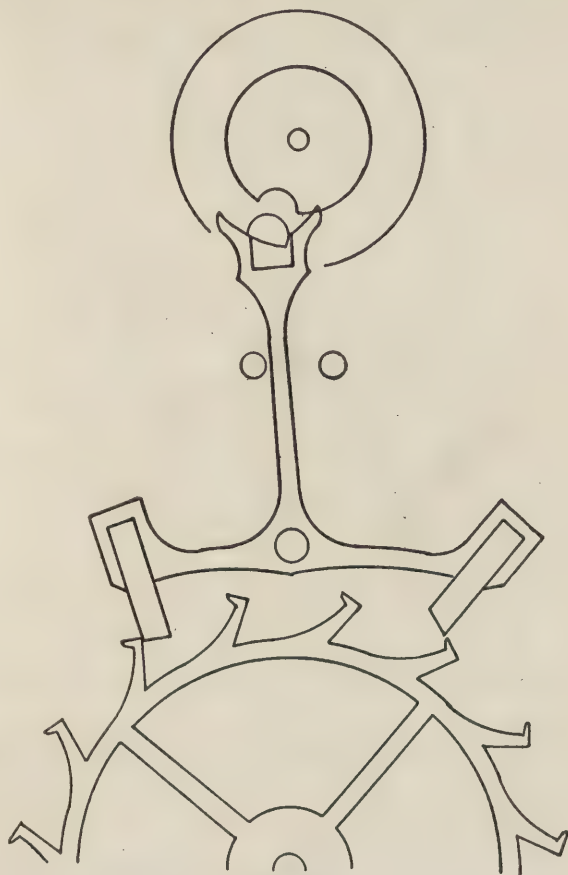

Fig. 45.

tact with the face of the jewel pin, thus preventing over banking.

Fig. 45 shows exactly the above condition. In this figure the jewel pin is in the same position as in Fig. 44, but the

fork is moved to the right, away from the banking; the guard pin is not shown, not being necessary in describing this action. It will be noticed that further movement of the fork to the right is prevented by the jewel pin, and that this also prevents unlocking the escape tooth.

CORRECT POSITION FOR IMPULSE PIN.—The fork and jewel pin actions can not be readily seen in the watch; the workman is therefore compelled to rely to some extent on
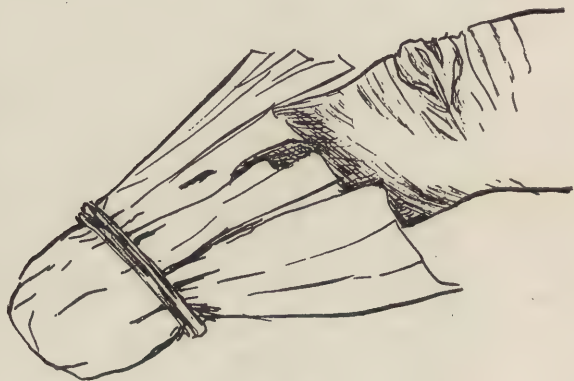

Fig. 46.

the sense of touch. How this may be done will now be explained.

Prepare a tissue paper finger-cot as follows: Take a piece of tissue paper about $2\frac{1}{2}$ inches square; fold it over the top of the index finger of the right hand, securing it with a light rubber band, as shown in Fig. 46. The purpose of this cot is to act as a shield. It permits the finger being placed upon the balance without danger of smearing it.

Placing the finger lightly on the balance, bring the escapement to the position shown in Fig. 47. Now move it in the direction indicated by the arrow, until the escape tooth is released by the discharging stone and a tooth drops on the
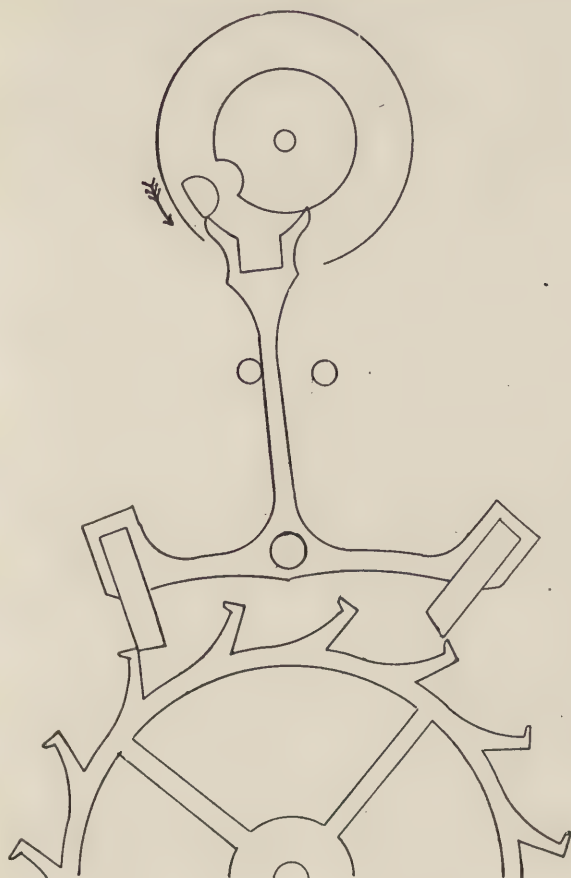
Fig. 47.

receiver. Stop *instantly* at this point. Press the fork lightly to the right. If the escape unlocks with this action, as shown in Fig. 48, the jewel pin is too far back and should be brought forward.

Fig. 48 shows this condition. The fork is shown pressed away from the left banking until it is arrested by the left horn coming in contact with the face of the jewel pin; but
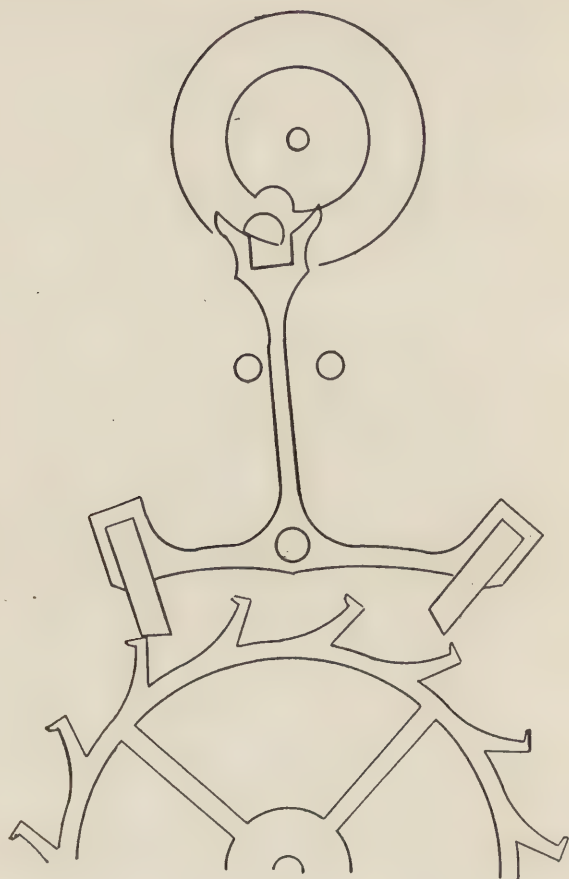
Fig. 48.

before this has taken place the escape tooth has been un-
locked and passes on to the impulse face of the pallet stone.

When the impulse pin is too far forward, there are two
methods by which it may be determined. The balance may
be taken out and the escapement banked to drop; that is,
the bankings closed up so that the escape wheel will not be
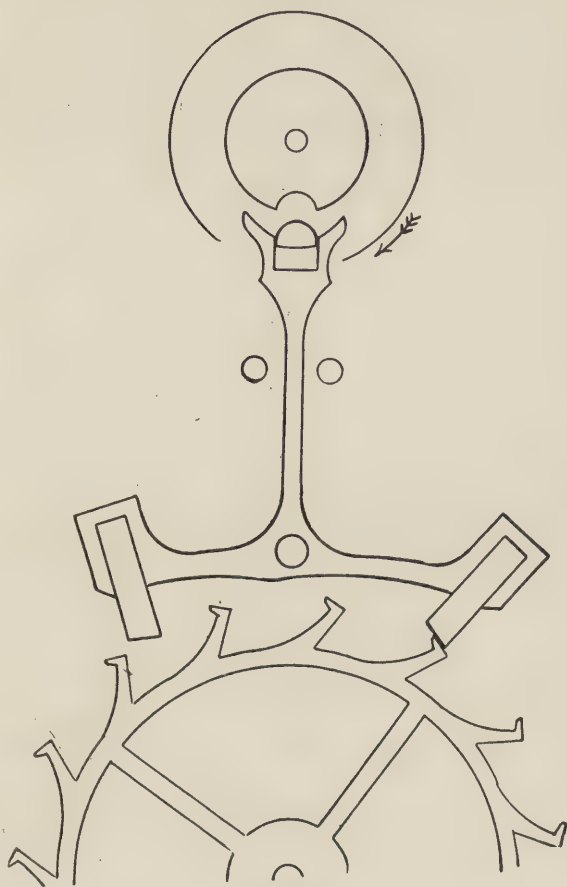released at either side; now open them until the wheel will

Fig. 49.

be barely released. Leaving them in this condition, replace the balance in such a position that the impulse pin shall be away from the fork. If, on rotating the balance, it is found that the impulse pin will not enter the fork slot, it is evidence that it is too far forward.
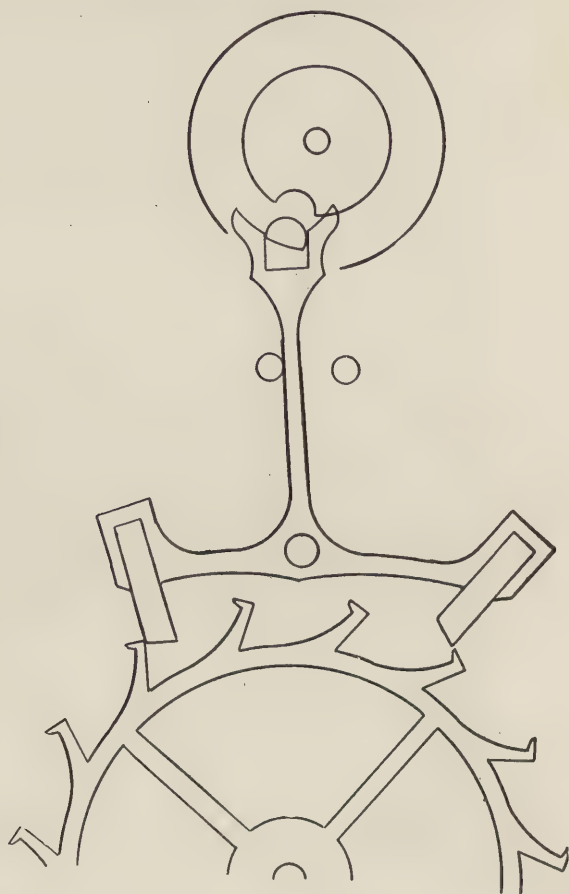
Fig. 50.

Another way of testing this is by banking to drop while the jewel pin is in the fork slot. If, after doing this, the jewel pin will not be released by the fork slot, it is evidence that the pin is too far forward.

Fig. 47 clearly illustrates the first method. The escapement is banked to drop; the roller is assumed to be moving

in the direction indicated by the arrow, but the impulse pin is arrested in its motion by the end of the fork horn. It must be quite evident that if the pin should be moved back so as to clear the horn, the roller might continue its rotation. Fig. 50 shows the escape wheel, pallets and fork in the same position as in Fig. 47. The impulse pin here is prevented from leaving the fork slot for the same reason that it is prevented from entering it in Fig. 47.

In either case, opening the bankings would allow the pin to enter or leave the slot; this, however, would give too much slide. This is frequently done, but is entirely wrong. At the locking point, the roller pin should just pass out of the fork slot without shake; the necessary freedom is given by opening the bankings slightly. Any opening of the bankings beyond this imposes unnecessary work on the balance.

When, in an escapement banked to drop, a banking is opened it allows the locking face of the pallet stone to slide along the locking corner of the wheel tooth; this is slide—sometimes called run. A perfect understanding of the difference between the terms lock and slide should be acquired.

Lock is the amount that the locking corner of a pallet stone projects beyond the locking corner of an escape tooth at the instant the drop takes place. Lock can only be changed by drawing out, or pushing in, one or both of the pallet stones. Opening or closing the bankings produces no change in the lock.

When a properly adjusted escapement is in action a tooth drops on the locking face of a stone; at this moment the fork is a slight distance from one of the bankings; in its further movement the locking face of the stone slides along the escape tooth until the fork is arrested by the banking. This is the slide.

The slide may be increased by opening the banking or decreased by closing it, but these operations produce no effect whatever upon the lock.

Fig. 51 will serve to illustrate the difference between the lock and slide. In this figure the amount of slide is exaggerated for the purpose of making it more readily distinguishable from the lock. The fork and pallets in full lines
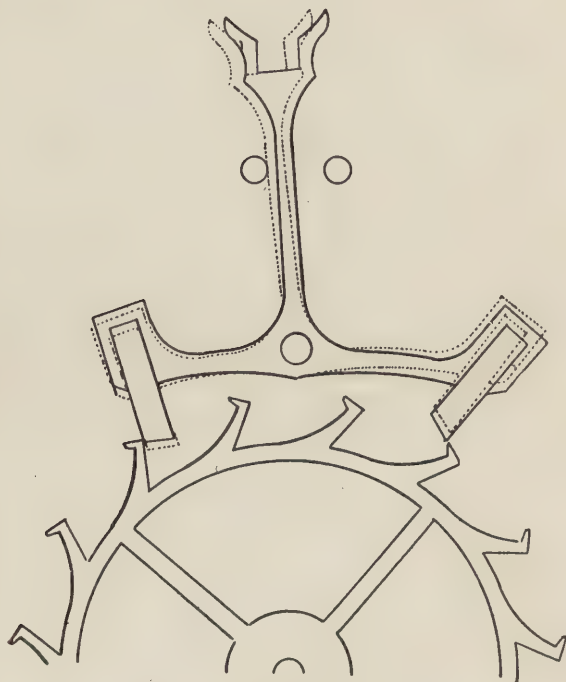

Fig. 51.

show the escapement at the lock; the broken lines show it after the slide has taken place.

The combination of lock and slide is sometimes called full lock; this is misleading; quite as much so, and quite as inappropriate, as it would be to call the combination of width and thickness full width.

THE SAFETY ACTION.—The guard pin in a lever escapement is purely a safety device. It could be dispensed with without impairing the time keeping quality of a watch, provided the watch was not subjected to any sudden or rapid motion. In order that it may be perfectly reliable as a pocket time-piece a guard pin becomes a necessity. During the free excursion of the balance in the interval between two impulses, the combined action of the guard pin and roller edge prevents the fork going out of position to receive the impulse pin. Without this safety provision a sudden motion given the watch would be liable to cause what is generally called over-banking, more properly speaking, going out of action.

When the impulse pin leaves the fork slot, the first part of the safety action is secured by the impulse pin and the fork horn. This is due to the fact that the passing hollow cuts away a part of the roller edge and while that cut-away part stands in the path of the guard pin some other means must be provided to prevent going out of action.

Fig. 52 illustrates the above condition. In this figure the roller is moving in the direction indicated by the arrow. The guard pin, 1, is just about to leave the roller edge and enter the passing hollow. Almost immediately the impulse pin will strike the right side of the fork slot, moving the fork and unlocking the escapement. The impulse pin will then be embraced by the fork slot.

In this drawing the passing hollow is not in position to release the impulse pin until it has been embraced by the fork slot. The passing hollow, however, is rarely as narrow as represented in full lines. As a matter of fact, it would not be practical to make it so. It will be seen that if the passing hollow was as wide as represented by the broken lines, the safety action at the point shown in Fig. 52 would be between the fork horn and the impulse pin. If the fork horn should be cut off entirely, as represented by
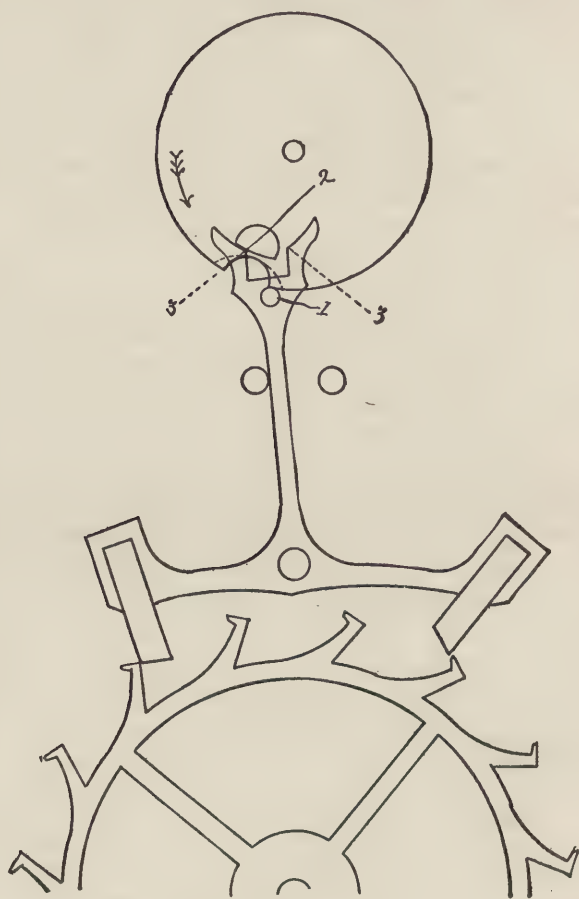
Fig. 52.

the broken lines, 3, 3, the safety action would still be per-
fect. The passing hollow, in Fig. 52, represented by broken
lines, is wider than is necessary. A passing hollow of a
medium width would answer the purpose quite as well.
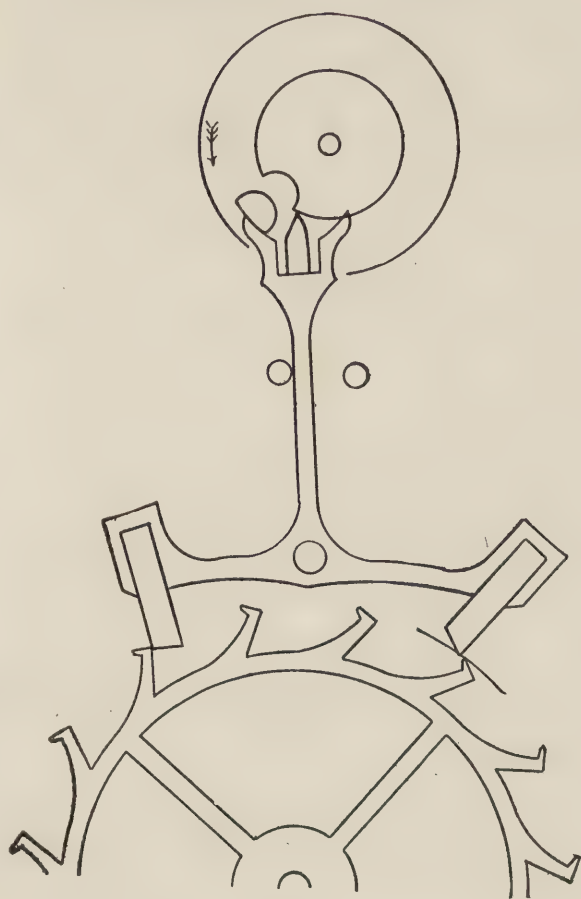When the impulse pin is made with a circular face, as

Fig. 53.

shown, the passing hollow may be left wider without impairing the action, but when the face is flat and the passing hollow wide, the action can not be so nicely adjusted. A double roller should always have an impulse pin with circular face. This condition will become apparent when we

reach the description of the double roller escapement. In view of the above, long horns on a single roller escapement are more ornamental than useful.

Fig. 53 shows how the safety action takes place in the double roller escapement under similar conditions to those prevailing in the single roller shown in Fig. 52. In Fig. 53 the roller is moving in the direction indicated by the arrow and the passing hollow is approaching the guard pin. It will be seen that the impulse pin is still some distance from the fork slot and that before it can enter the safety action between the guard pin and roller will have ceased. Therefore, a fork horn to provide this safety action is necessary. Otherwise it would go out of action.

When the guard pin, in Fig 53, first comes opposite the passing hollow, the impulse pin will still have a considerable distance to travel before contacting with the fork. It is, therefore, evident that a much greater proportion of the safety action occurs between the impulse pin and fork horn in the double roller than in the single roller escapement.

The curves of the fork horn faces in both Figs. 52 and 53 are arcs of circles having the same radius, but the centers from which they are described are not in the same location. These arcs are so described that when the fork lies against either banking the curve of the fork horn, at that side, coincides with the circle described by the face of the impulse pin in its path. In the single roller escapement this is of little importance; but in the double roller it is a great advantage, owing to the fact that a greater portion of the safety action must be provided for by the fork horn.

It is a common practice for manufacturers to form fork horn hollows from a common center, in which case the radius must be greater than when two centers are used. These curves are apt to be so wide and to vary so widely from the path of the impulse pin that—especially in a double roller escapement—the safety action may be some-
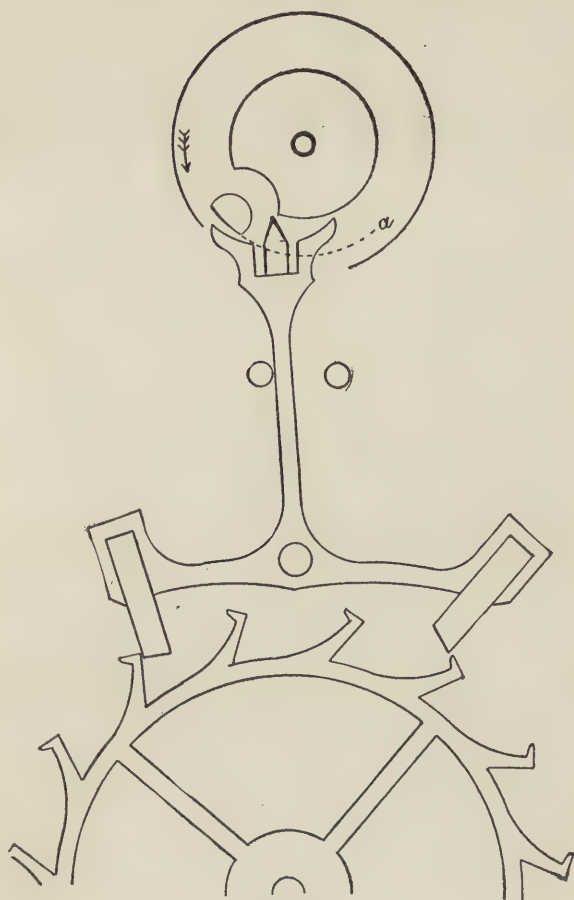
Fig. 54.

what uncertain. Add to this a wide passing hollow and we have a combination liable to make trouble and be extremely puzzling to the repairer.

Fig. 54 illustrates the evil to be apprehended from the condition above described. In this sketch the escapement

is shown in the same position as in Fig. 53. The particulars in which the escapements differ are: In Fig. 54 the fork horns are curved from a common center, and the passing hollow is wider than in Fig. 53. It will be observed that the curve of the left fork horn does not coincide with the path of the guard pin, which is the broken line, a. The corner of the fork slot is tangent to that line, while the extreme end of the fork horn is some distance from it. Under these conditions any sudden jar might throw the fork to the right, thereby wedging the guard pin against the edge of the passing hollow, unlocking the escapement and stopping the watch. This is made clear in Fig. 55.

Fig. 55 shows the roller in the same position as in Fig. 54. The fork is assumed to have been thrown to the right by a sudden jar. It will be seen that the escapement is now unlocked, an escaped tooth having passed down for a slight distance on the impulse face of the receiving stone. When this occurs and the roller is moving in the direction of the arrow, a, it will cause a wedging of the parts that must stop the watch, possibly break the impulse pin, or either bend or break the balance pivot. If it is moving in the direction of the arrow b, it may only trip—check the motion—and pass on, but in that case the escapement must unlock momentarily causing the watch to lose time to a greater or less extent according to the frequency of its occurrence.

It is not intended to imply that every fork, the curve of the horns of which are developed from a common center, will produce the condition described above. It is only intended to show what may ensue, and to caution the workmen against neglect in observing this particular feature.

This condition may readily be detected by following the directions below. Turn the balance slowly in either direction until an escape wheel tooth drops on a pallet stone, then press the fork lightly toward the center position—away
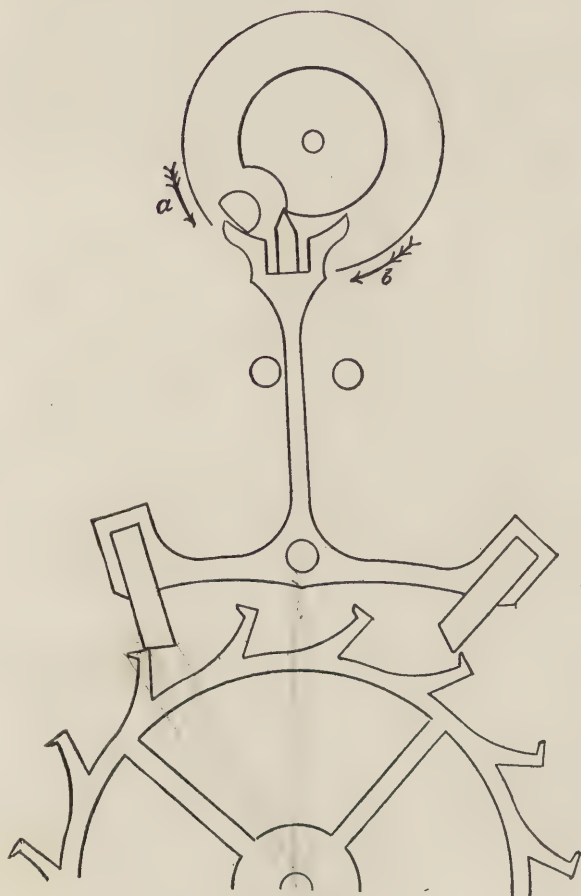
Fig. 55.

from the banking—continuing to turn the balance for about ¼ revolution. If the condition described prevails the escapement will unlock. Now make the same trial on the other stone.
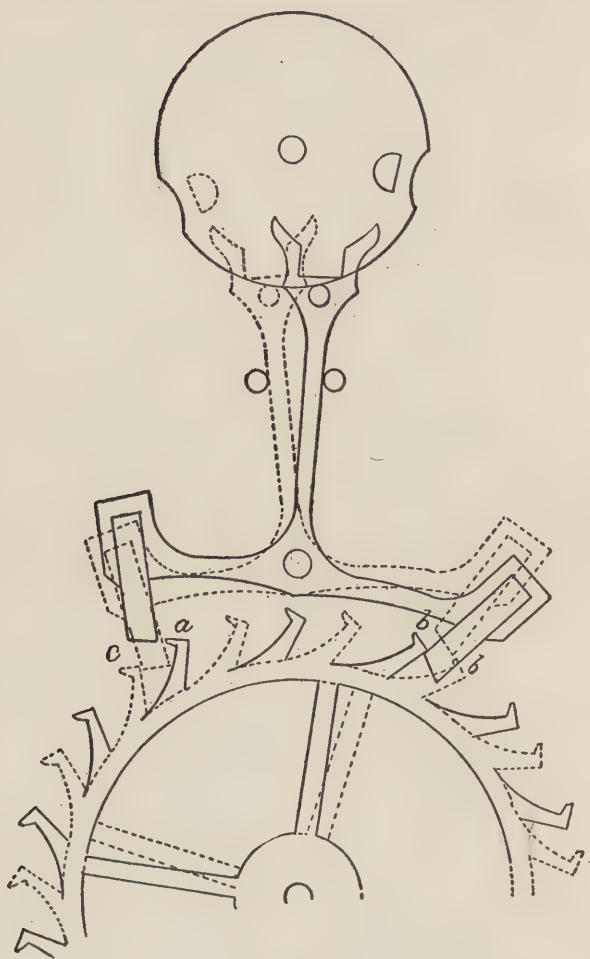
Fig. 56.

THE GUARD PIN AND ROLLER ACTION.—In a single roller escapement the guard pin should be perfectly upright. Bending it forward, backward, or sidewise to adjust the roller shake is not permissible. The evil of that practice will be demonstrated further on.

Fig. 56 shows a single roller escapement banked to drop. In the escape wheel, the full lines show the tooth, a, of the escape wheel released from the receiving stone. The broken lines show tooth, b, after it has passed across the impulse face of the discharging stone, and tooth, c, has locked on the receiving stone. It will be observed that the fork lies against the bankings at both sides and that the guard pin contacts with the roller at both sides also. This is called, "Banked to Drop—No Shake—No Slide," which means that it is banked without either shake between the roller edge and guard pin or slide on either pallet stone.

Fig. 57 shows the double roller escapement in the same condition as the single roller in Fig. 56. These last two figures show both fork and roller in two positions. Now turn to Fig. 64 which shows the fork in two positions and the roller in one. In this figure the fork, in full lines, is just about to embrace the impulse pin. The safety action which has been, until this instant, between the fork horn and the face of the impulse pin now ceases. In the fork, shown in dotted lines, the safety action is between the edge of the safety roller and guard pin. (Dart).

Fig. 58 shows a single roller, Fig. 59 a double roller. By comparing the two it will readily be seen that the single roller is more liable to allow the fork to go out of action than the double roller, and why this is the case. By comparing, in Fig. 58, the broken line, aa, which indicates the path of the guard pin, with the broken line, bb, which is the path it should take, it will be seen that it only requires a slight difference, such as might arise from a pallet arbor with too much side shake, to allow the fork to go out of action, a condition which is represented in this figure. The roller is moving in the direction of the arrow, and the fork should be at the right with its slot in position to receive the impulse pin. But in going out of action it has passed to the left. The pin is arrested by coming in contact with the outside of the fork horn, and the watch immediately stops.
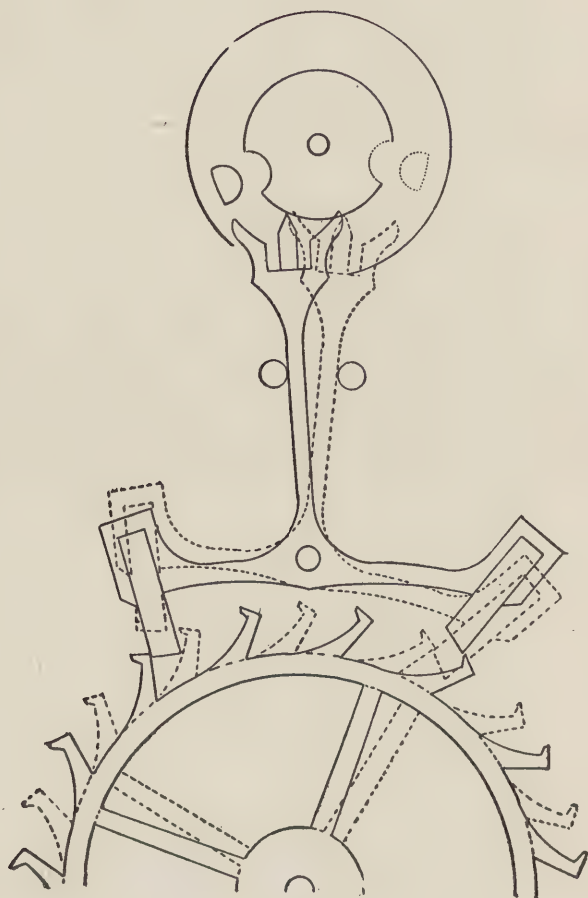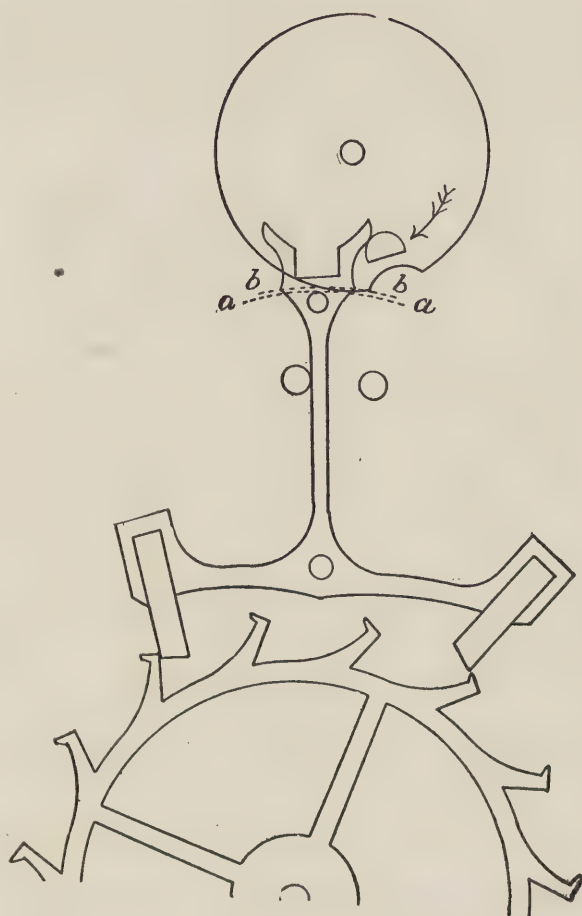
Fig. 57.

Fig. 58.

Now turn to figure 59. The two broken lines, aa, and bb, are in the same relation to the guard pin that they are in Fig. 58. Although the fork, in Fig. 59, is thrown against the roller edge, it can not pass, and the escapement is not unlocked. It, therefore, follows that a slight error which might cause a single roller escapement to go out of action, might not seriously affect a double roller.

UNEQUAL ROLLER SHAKE.—The guard pin should be perfectly central with the fork slot under all conditions. It should never tilt from the perpendicular in a single roller escapement, and in a double roller escapement, a line drawn from the point of the dart to the center of the pallet arbor should pass through the center of the fork slot and be parallel with its sides.

Fig. 60 shows an escapement with unequal roller shake. The full lines show an escape tooth locked by the receiving stone, the guard pin touching the left edge of the safety roller. When the lock takes place on this escapement the locking corner of the tooth strikes the face of the stone at the position shown by the broken line parallel with it, but in order that the dart should free the safety roller the left banking was opened from the position shown in a dotted line to that shown in a full line. This allowed the pallet stone to slide down on the tooth until the locking corner of the tooth was at the point, b, and the locking corner of the stone at point, a. Now inasmuch as the banking pin must be moved still more to give sufficient freedom to the safety roller, the amount that the stone projects below the locking corner of the tooth will be still more increased to the detriment of the escapement, and entailing a loss of power.

The fork shown in broken lines in the same figure is in the position in which a tooth is released by the receiving stone and is properly locked on the discharging. Examining the position of the dart with reference to the safety roller we find that it is at some distance from its edge.
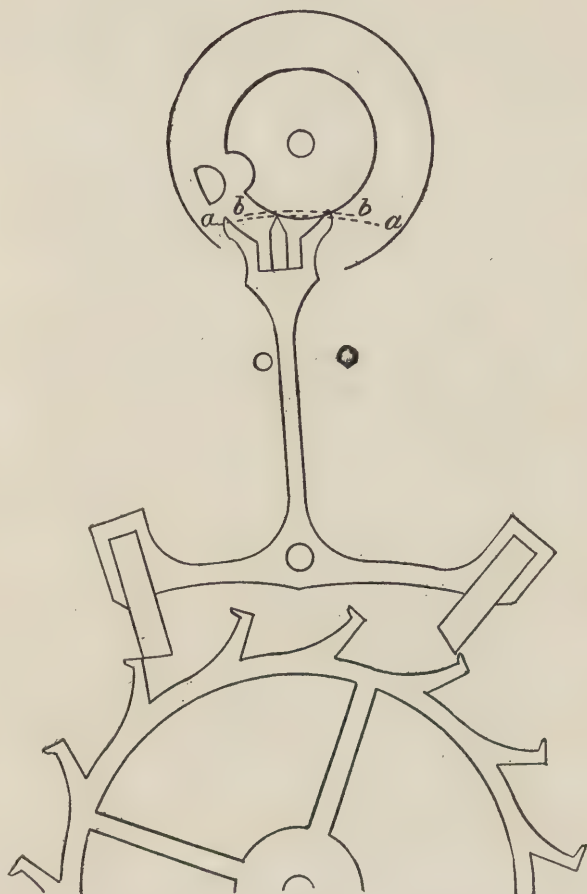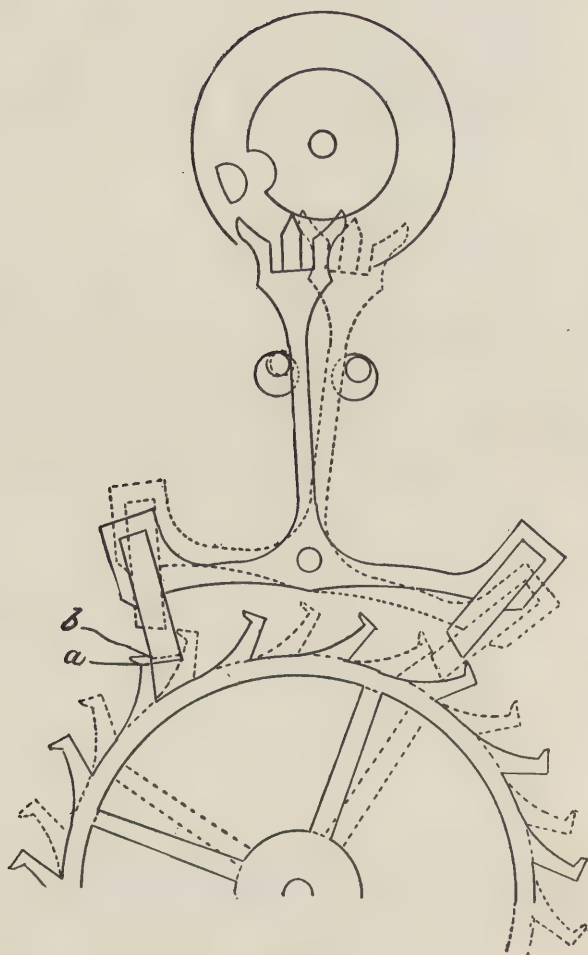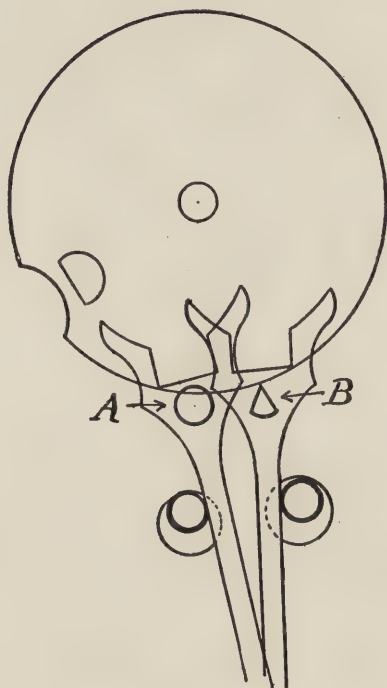
Fig. 59.

Fig. 60.

Fig. 61.

This is the condition technically called "Out of Angle." There are several means resorted to for its remedy. One is to bend the guard pin as shown in Fig. 62. This, however, throws it out of line with the center of the fork slot and should not be tolerated. Another method is to draw out the discharging stone and push in the receiving stone a sufficient amount to correct the out of angle; but in moving a pallet stone in or out, several changes are produced in an escapement and it should never be done without previously thoroughly examining the escape wheel and pallet action so as to avoid the danger of creating another error
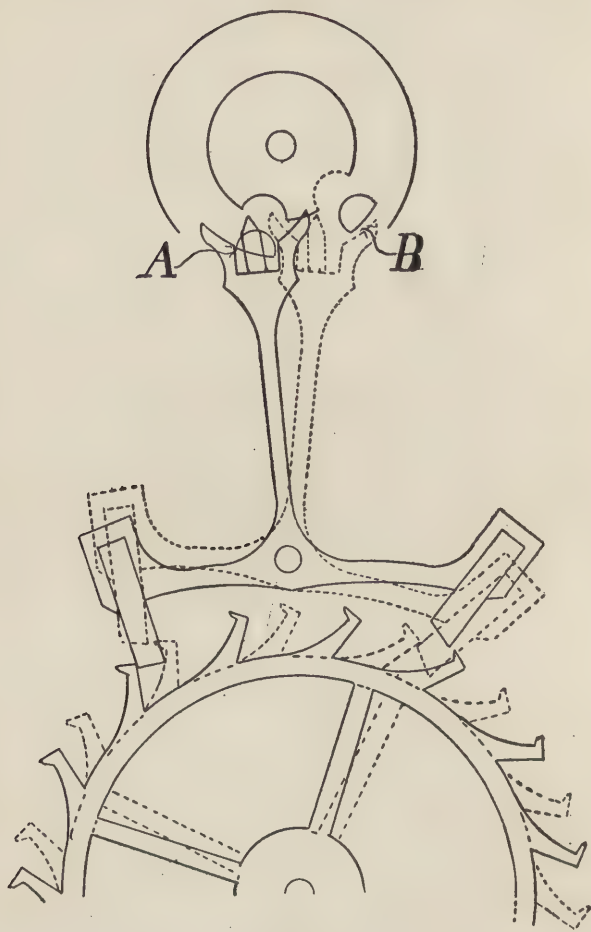
Fig. 62.

Fig. 62 shows the effect of bending the guard pin out of line with the center of the fork slot. In this drawing the guard pin is bent to the left to correct the defect in the safety action shown in Fig. 60. This alteration leaves the

escapement with correct lock and slide. The safety action is correct so far as the guard pin and roller are concerned, but the impulses, delivered by the pallets to the impulse pin, are at unequal distances from the line of centers. The greatest portion of the impulse on the receiving stone is delivered after the line of centers has been passed; the least amount on the discharging stone. A condition of this character would seriously affect isochronism and position adjustment. A more serious error has also been created. Referring to Fig. 62 it will be seen that the corner, A, of the fork slot will not permit the impulse pin to pass freely out of it, while at the other side at the point marked, B, there is more room than required. This might be remedied by grinding away the left horn of the fork, but it would still leave the unequal impulse.

The condition just described, however, is not the most serious one resulting from bending the guard pin to equalize the roller shake. The escapement is liable to do what is technically called "Trip." The escapement shown in Fig. 62 would do this. If—when the escape is locked on the discharging stone and the point of the guard pin is opposite the passing hollow—the fork should be pressed to the left, the tooth might unlock from the discharging stone. .

Fig. 66 illustrates the above. In this figure an escapement is shown with the guard pin bent as in Fig. 62. The roller is assumed to have moved from the position there shown to the position shown in Fig. 66. That is, until the passing hollow is opposite the guard pin. In this position the fork has been pressed to the left. The safety action between the impulse pin and fork horn fails to arrest the movement of the fork until the escapement has unlocked on the discharging stone, as shown.

Moving the pallet stones for the sole purpose of changing the roller shake is a method often practiced, but it is not to be advised. It necessitates more time and jeopardizes the escapement action. A pallet stone can not be moved with-

out altering the escapement in at least four particulars: Impulse, draft, lock and drop.

The simplest and best method of making the alteration is to bend the fork. This alters no other functions of the escapement.

Bending a fork is an operation of which many repairers stand in awe, but if done carefully it is attended with but little danger.

Before attempting to bend a fork ascertain whether it is of sufficiently low temper to permit of doing so with safety. It is not necessary to disfigure a piece made of steel in order to ascertain whether it is hard or soft. Use a fine, sharp file. Place it on the piece to be tried—on some part that is not polished. Without actually moving the file, exercise a gentle forward pressure. If the steel is hard it will offer no resistance to the movement of the file. If it is not hard the file will cling to the steel, more or less, in proportion to the temper. A little practice will enable anyone to become expert at this method. It is rarely that a fork is too hard to permit bending, but should it be, there remains but one of two courses to pursue: Let it alone or take the stones out and draw the temper. There is no objection to reducing the temper of a fork to a sufficient amount to allow it to be bent with safety.

Fig. 63 shows where the bend should be made. If it is done at the point, a, a very little will be sufficient.

There are several methods practised in bending a fork; some preferring one and some another. It may be set edgewise on a soft metal block and struck with a punch. It may be bent between dies or jaws of pliers especially shaped for the purpose, or it may be pened with a hammer.

To summarize the conditions necessary for correct safety action: The guard pin central with the fork slot; the sides of the fork slot parallel and of equal length; the inside curves of the fork horn of the proper arc and equal in relation to the fork slot; the impulse pin squared in front and

upright; the edge of the safety roller perfectly polished and free from imperfection; the escapement in angle.

GUARD PIN TOO FAR FORWARD.—When the guard pin is too far forward the bankings are sometimes opened to allow the roller to pass. This method should never be re-
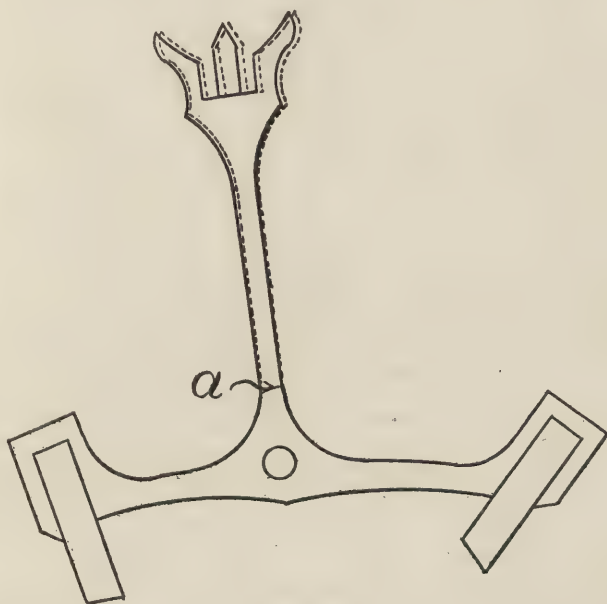

Fig. 63.

sorted to, for the reason that it increases the slide. It also increases the angle of contact between the impulse pin and fork, both of which incur a loss of power.

Fig. 65 illustrates this condition. This figure shows a single roller escapement. The single roller is used for the reason that it is desired to show how that form of escapement can be corrected for errors caused by the incorrect distance of the guard pin from the pallet center.
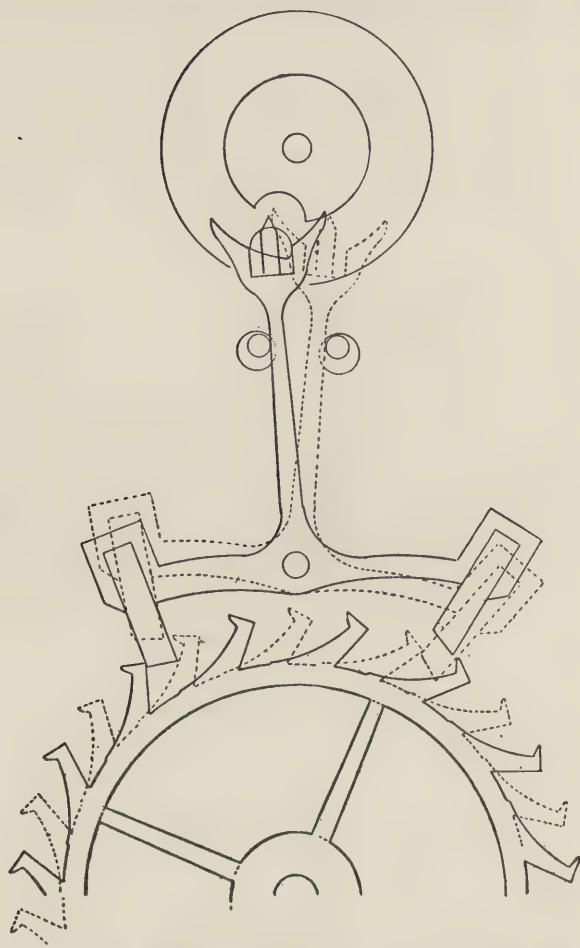
Fig. 64.

It will be observed that, in order to clear the guard pin from the roller edge, the bankings have been opened, thus making the slide excessive, as indicated by the position of the receiving stone with relation to the tooth which it locks. This imposes additional work upon the balance in unlocking the
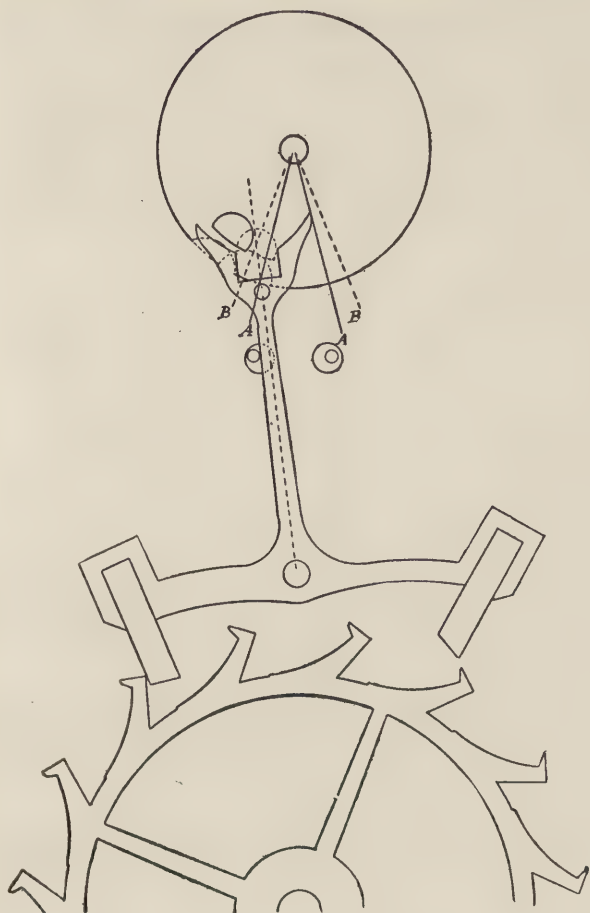
Fig. 65.

escapement. It also, as has already been pointed out, in-
creases the angular distance during which the impulse pin
and fork remain in contact. The full lines, AA, indicate the
angle of contact as it should be; the broken lines, BB,
indicate the angle of contact with the banking open to allow
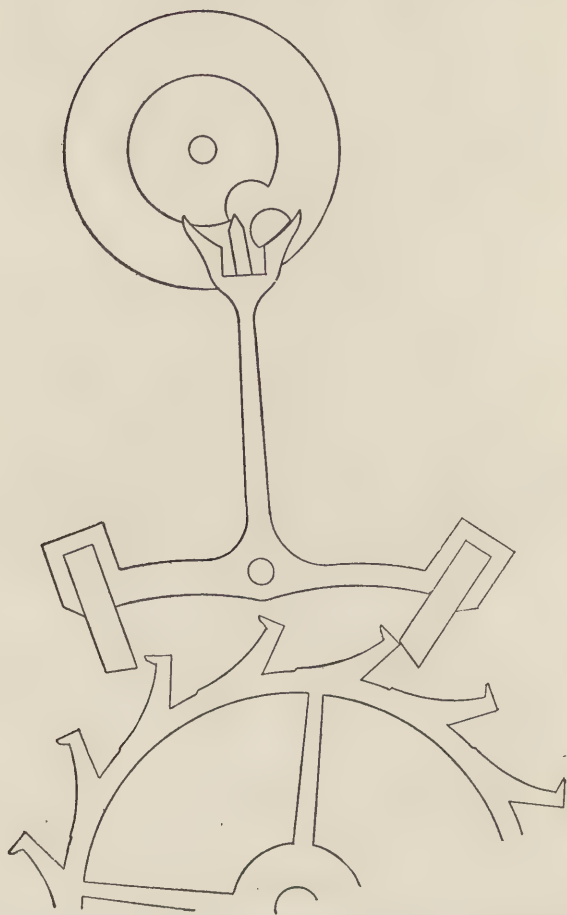the guard pin to clear the roller edge.

Fig. 66.

The angle of impulse of a roller is where the two radii from the roller center through the impulse pin center intersect lines running from the pallet arbor through the center of the fork slot. In Fig. 65 this angle is shown in broken

lines. It will be noticed that the lock in this figure is excessive. If reduced to the proper amount the impulse angle would be as represented by the full lines, AA.

Experience has taught us that a short arc of impulse produces better results than a long one. We have reduced the action arc of impulse of the fork, within the last half century, from 12 degrees to eight and a half; the active impulse of the roller from 45 degrees to 30.

To remedy a guard pin in a single roller escapement when too far forward proceed as follows: Push the guard pin through a small piece of tissue paper, the object being to prevent marring the polished face of the fork. With a fine file, dress the pin to a point as shown at B, Fig. 61. A is the pin before being dressed down. It may be reduced as much as necessary without injury to the safety action. In fact a V-shaped safety pin is superior to a cylindrical one in this particular.

In the double roller escapement an alteration in the length of the guard pin-dart—is so simple that instruction is deemed unnecessary.

GUARD PIN TOO FAR BACK.—When the guard pin, in a single roller American watch, is too far back it can readily be remedied. Drive the guard pin out, broach out the hole in the fork and insert a larger pin. In many Swiss watches there is no guard pin, its place being taken by a pointed projection on the fork. In this case a larger roller may be substituted, or the fork may be stretched. Stretching the fork would probably necessitate grinding out the fork horns, which may be done with a wire charged with diamond powder.

The guard pin in Fig. 59 is rather short. It is short the same amount as the guard pin in Fig. 58 is too far back. As has been previously explained the fork in Fig. 58 would go out of action, but while that in Fig. 59 would not, yet it would improve its action by stretching the dart,

THE ESCAPE AND PALLET ACTION.—The escape and pallet action is the most intricate function of the escapement. A thorough knowledge of it calls for thoughtful study. Yet there is nothing about it that can not be mastered by the painstaking student. In treating it, it is deemed best to divide it into five branches: Impulse, Draft, Lock, Slide, Drop.

IMPULSE.—An escape tooth, in delivering impulse to a pallet, moves in an arc of a circle, this arc being 12 degrees.

In the ratch tooth escapement all the impulse is on the pallet; otherwise the same rules apply to it as to the club tooth. A brief description of the ratch tooth escapement will be given later on.

The chief advantage of the club tooth escapement over the ratch tooth is that the former can be constructed with less loss of power from drop. A minor advantage is that there is less liability of wedging the guard pin against the roller edge when the train is reversed as sometimes occurs in setting the hands backward.

In the club tooth escapement, the circular impulse is divided between the wheel tooth and the pallet stone. This division is in various proportions; usually within the narrow limits of four-tenths to the tooth and six-tenths to the stone, and equal amounts to both.

Fig. 67 illustrates a good type of action. In this drawing an escape tooth is shown in four positions while delivering impulse to the receiving stone. It will be observed that when the tooth begins to pass over the stone, as at A, the impulse faces diverge from each other. In this position the locking corner, only, contacts with the impulse face of the stone, and from this point the faces diverge backwards to the locking corner of the stone. At B, the tooth is shown, having passed further along on the impulse face of the stone and a divergence at a somewhat less angle is seen. As the impulse progresses the faces of the tooth and stone coincide in the position shown at C. From that point the
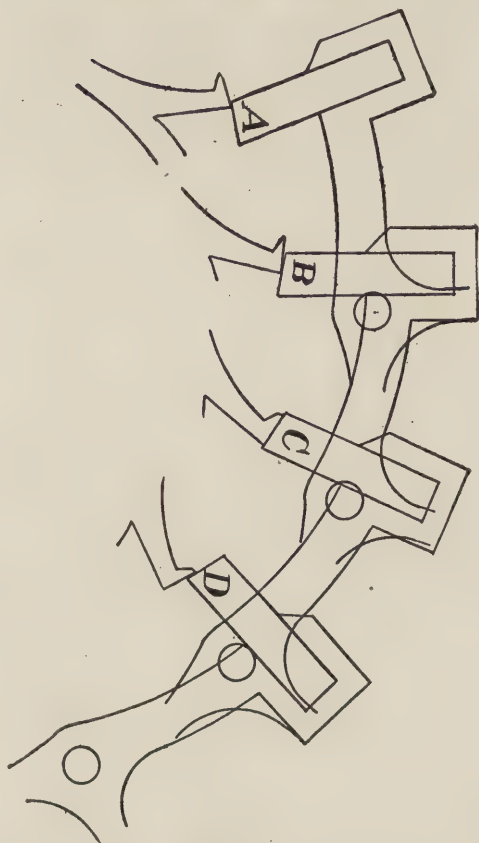
Fig. 67.

divergence begins to appear in the reverse direction, as at D, and continues until the tooth is released. This is called a natural divergence. It is less productive of abrasion or wear, and also reduces friction.

An alteration made in an escapement by moving a stone in or out changes the impulse action.

Fig. 68 shows the effect of changing the position of a receiving stone. In order to demonstrate the actual result of moving a stone this drawing has been made with unusual
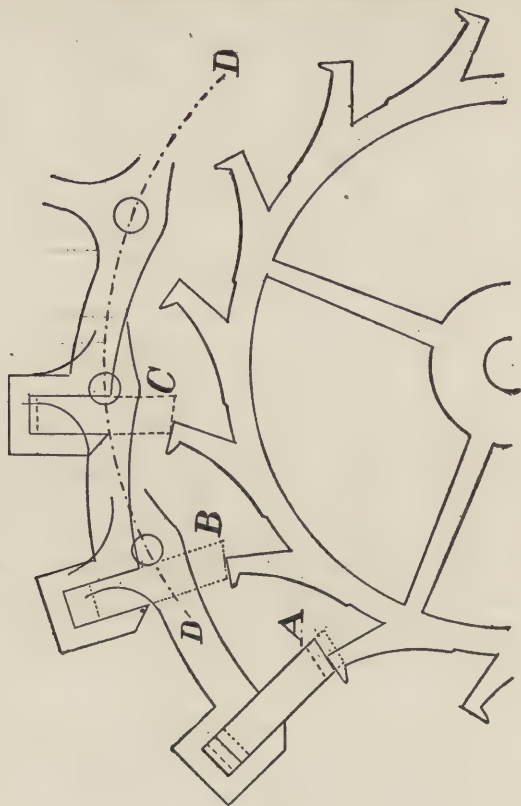
Fig. 68.

care. The pallets are drawn in three positions in relation
to the wheel. At A, the stone is shown in correct position,
in full lines. It is shown in dotted lines, drawn out. It is
shown in broken lines, pushed in. The back, as well as the
impulse face of the stone, is indicated by similar lines. The
centers of the three pallets are equi-distant from the center
of the escape wheel, as indicated by the line DD. The posi-
tion at A is normal; that at B, with the stone drawn out to
the dotted line; that at C, with the stone pressed in to the
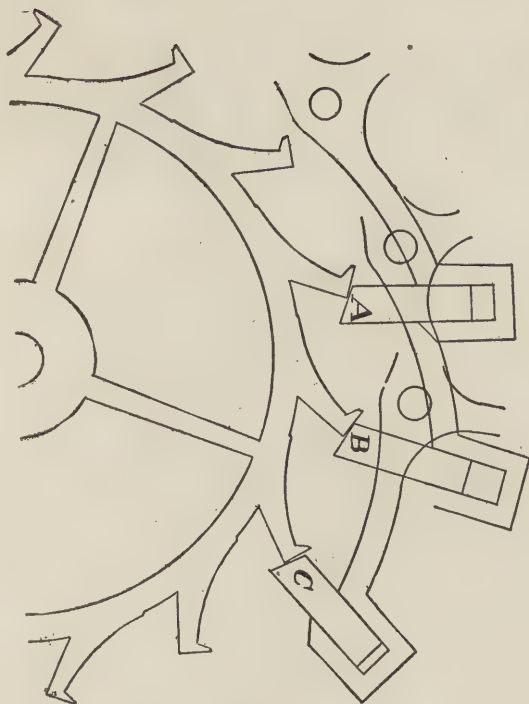broken line.

Fig. 69.

It will be seen that moving the stone outward, as at B, increases the divergence backwards from the locking corner of the wheel; that moving the stone inward, as at C, produces a divergence in the opposite direction. The latter is considered a bad action for the reason that the locking corner of the stone scrapes across the impulse face of the tooth wearing it away rapidly.

Moving a discharging stone produces results directly opposite to those resulting from moving the receiving stone.
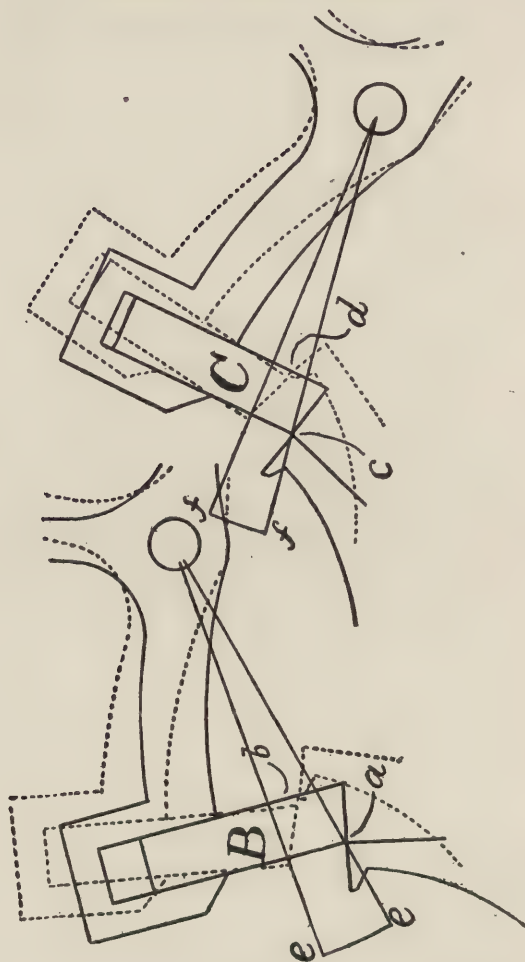
Fig. 70.

Fig. 69 shows the effect upon the impulse of moving a discharging stone. At C, where the stone is pushed in the divergence is excessive; at B, where the stone is drawn outward the divergence is in the wrong direction; at A, where it is in proper position the divergence is natural.

There is another result from moving a pallet stone which must not be overlooked. It changes the extent of the arc of vibration of the pallets. In other words—changes the lift.

The term "lift" is applied to the thrust given to the pallets by an escape tooth. In the lift, the pallets swing on their own center and the extent of that swing is called the arc of vibration. It has been explained that the circular impulse is measured from the center of the escape wheel and is divided between an escape tooth and a pallet stone. The lift is measured from the pallet center and is also divided between an escape tooth and a pallet stone.

Fig. 70 shows the variation in lift caused by changing the position of a receiving stone.

The positions of the stones, B and C, are identical with those similarly marked in Fig. 68. This is to say, they are located in the same position at B Fig. 70 as at B Fig. 68; also at C Fig. 70 as at C Fig. 69. Both wheel and stone are shown in full lines at the beginning of the lift and in dotted lines at the end. Referring to B, the lift begins at a and ends at b. The lines ee radiating from the pallet center intersect the pallet stone at the locking corner at the beginning and end of the lift. Referring to C it begins at c and ends at d. The lines ff intersecting at the locking corner. Now it is quite evident that the angle inclosed by the lines ee is greater than the angle inclosed by ff, which shows that drawing out a receiving stone increases the lift.

Another result brought about by moving a receiving stone would seem anomalous. It is this: While drawing out the receiving stone deepens the lock on both stones, yet it deepens the lock more on the discharging stone than on the receiving. Drawing out the discharging stone has the opposite effect, deepening it more on the receiving than on the discharging.

Fig. 71 probably shows more clearly how the difference in the lift is produced. The pallets have both stones shown in two positions. The position with regard to the receiving
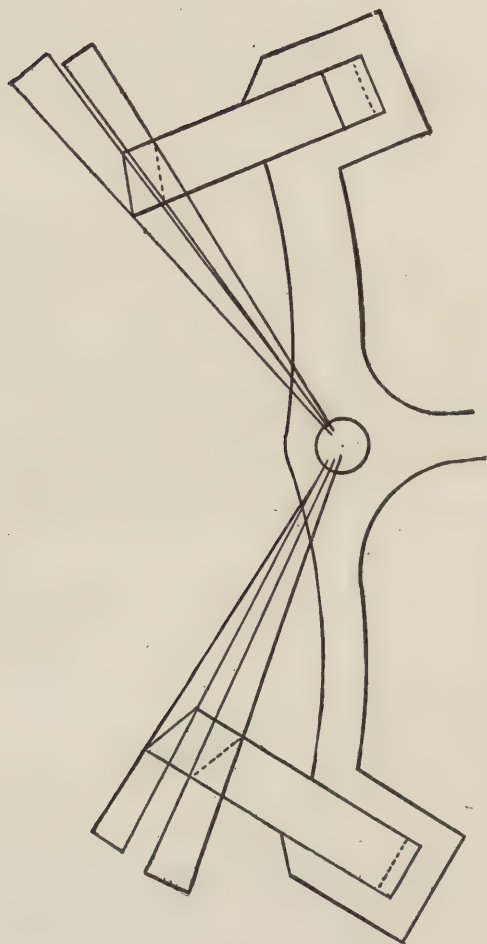
Fig. 71.

stone is identical with the position shown in Fig. 70. The dotted lines indicating the face and the back of the stone correspond with C Fig. 70 and the full lines with B in the same figure. In the discharging stone the same conditions are indicated by dotted, and by full, lines. This figure shows clearly that drawing out the receiving stone increases the impulse, while drawing out the discharging stone decreases it.

DRAFT.—The draft of an escapement is that power that draws the fork away from the roller after it has delivered an impulse. It is secured by setting the pallet stones at such an angle in relation to the direction in which the force exercised against the locking face is resisted, that it will draw the fork against the banking.

The term "resisted" is used for the reason that a misunderstanding on this point prevails to some extent.

The draft is determined by the inclination of the locking face of a pallet stone from a line drawn at right angles to a radius from the pallet center to the point of contact between the locking corner of the wheel tooth and the locking face of the pallet stone.

This detailed explanation of draft may at first sight seem confusing, but Fig. 72 will make it clear.

At A is shown what is known as "Tangential Locking." In this form the broken radial line a, from the wheel center to the locking point b, forms a right angle with the broken line c, from the pallet center to the same point. In the form shown at B, the broken radial lines d and e, do not form a right angle. This is known as non-tangential locking.

In the former case the force exercised by the escape wheel is directly towards the pallet center and the resistance to that force is precisely on the same line. In the latter case the force is directed as indicated by the dotted line f, while it is resisted in the direction of the broken line e. In other words, at the tangential locking the force and the resistance

are on the same line, while at b non-tangential, the force and
the resistance are on different lines. The resistance being
in the same direction in both cases, the draft angle must be
determined in relation to a radial line from the center of
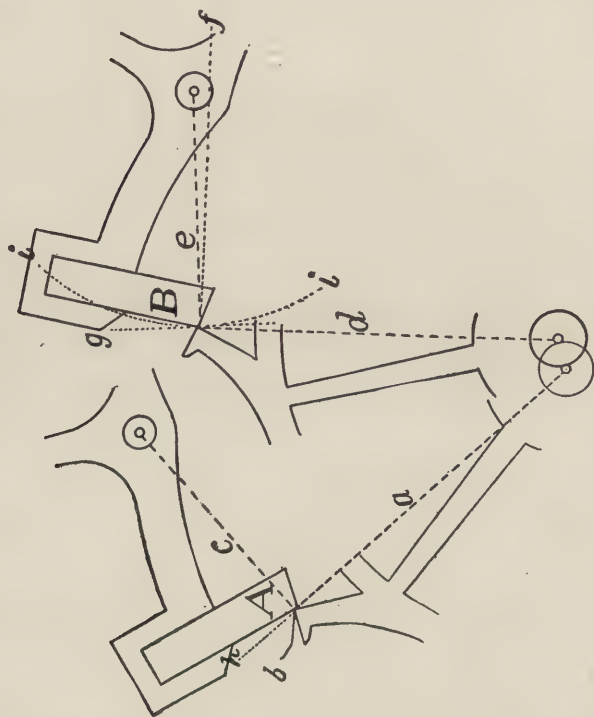the pallets to the locking point.

Fig. 72.

The dotted line g, is termed the tangential line, meaning
that it touches the arc ii at the intersection of the radial
line e, with it. The draft angle is laid out from this tan-
gential line. In the escapement shown at A, the broken

radial line a, is continued by the full line h, in order to show that the tangential and the radial, lines are in this case identical.

Insufficient draft is a serious error. Where it exists there is a constant liability when the watch is subjected to some sudden motion, of the fork leaving the banking and striking the safety edge of the roller, thus retarding the motion of the balance. It is a waste of time to attempt adjusting a watch having this fault.

A common method of testing the draft of an escapement is to lay the watch in a horizontal position, then draw the fork slightly away from the banking and see that it returns to its original position. The writer would recommend trying the banking under the most unfavorable conditions to which the watch is likely to be subjected in its owner's pocket. First, see that the watch is let down to the point it would have reached after a run of 24 hours then hold the watch in a vertical position. If the fork is poised it will make no difference what position the watch is held in so long as it is vertical, but if the fork is unpoised it should be held with the heaviest part lying in a horizontal line with its center. If the fork is without a counterpoise the arm would then be horizontal. In this case first try the fork by drawing it slightly away from the banking, while the fork is in horizontal position to the right. This will usually be trying it on the receiving stone. Then turn the fork to the left which will be on the discharging stone. The object of using this method is to insure it against insufficient draft. If the draft is not sufficient to draw the fork against the banking, under the conditions stated, it should be increased.

It is rarely that an escapement is found with too much draft. Should there be a suspicion that such is the case it can be easily determined: Take a small piece of wax and attach it to the fork by inserting it on the guard pin or in any other method that may suggest itself; then try the

draft as before. Judgment will dictate the additional weight that should overcome the draft.

Draft can sometimes be changed by tilting a pallet stone in its slot. This, however, cannot be done when the stone is closely fitted. Another method, in which the draft may be altered, is by pushing in one stone and drawing out the other.

Drawing out the receiving stone and pushing in the discharging increases the draft on both stones.

Drawing out the discharging and pushing in the receiving, decreases the draft on both stones.

That is, drawing out the receiving stone causes an escaped tooth to drop farther upon the locking face of the discharging stone, which of course increases the draft on that—the discharging—stone, but it also increases the lock, which must be remedied by pushing in the discharging stone. This causes a tooth to drop farther down on the receiving stone, increasing the draft. A slight movement of the stone in or out will change the draft to a considerable extent.

In changing a draft by this method extreme care should be used to avoid introducing other errors.

It should be borne in mind that drawing a receiving stone increases the drop on the discharging stone, but does not alter the drop on the receiving, but in pushing in the discharging, to correct the lock, the drop is decreased on the receiving stone.

It should also be borne in mind that drawing out the receiving stone increases the divergence of the impulse face of the wheel with that stone, and that pushing in the discharging stone increases the divergence on that stone in the same manner.

That is, drawing out the receiver and pushing in the discharger increases the divergence on both stones.

Pushing in the receiver and drawing out the discharger decreases it.

When the draft is altered by pushing and pulling the stones, that operation puts the fork out of angle, which must be corrected by bending. It would be advisable for the student to have an escapement for trial, in which he could move the pallet stones in and out in order to note the effect. Later on in this work, directions will be given for making a drawing of an escapement on tracing cloth, by means of which, the conditions just described, as well as many others, will be demonstrated.

Fig. 73 shows the effect on the drop, of moving a stone. At A, the pallets and wheel are shown in two relative positions. In the first position they are shown in full lines and the teeth marked 1, 2, 3, 4. The wheel is supposed to move forward when a tooth is released by the receiving stone. The pallets are then in the position shown in dotted lines and the wheel teeth, in dotted lines, are marked 1, 2, 3. In the drawing shown at A the drop is equal. The distance between the releasing corners of the receiving stone and tooth 1, as shown at a, is exactly the same as the distance between the releasing corners at b.

Now referring to the pallets shown at B, it will be observed that the receiving stone has been drawn out, as indicated by the black space in the pallet slot, and that the discharging stone has been pushed in, as indicated by the disappearance of the black space, that was shown in the discharging stone slot in pallets A. At B the escapement is shown under the same conditions as at A: Lock on the receiver in full lines; on the discharger in dotted lines. It will be plainly seen that the distance between the releasing corners at c is greater than at d. This is to say, that while the lock was equal with the stones in position, as at A, drawing out the receiving stone and pushing in the discharging made them unequal, as at B.

Fig. 74 shows a pair of pallets with the escape wheel teeth in three positions on each stone. The three positions are indicated by the escape wheel teeth shown in dotted
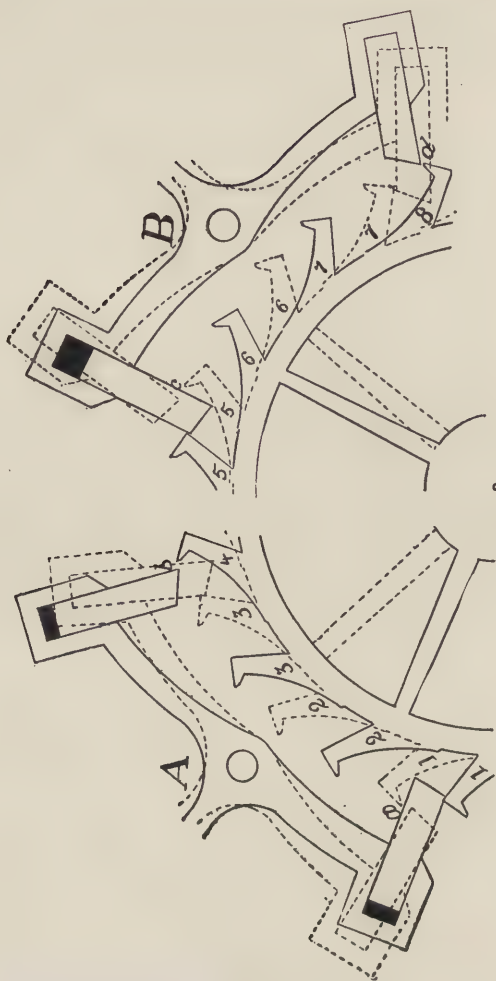
Fig. 73.

lines, in full lines, and in broken lines. From the points of contact are drawn, dotted, broken, and full lines running radially to the pallet center and at right angles to the radii. These lines are marked a, b, c, on the receiving side and d,

e, f, on the discharging side. The inclination of the locking faces of the stones toward these lines determines the draft. The drawing is for the purpose of showing the opposite effects produced by moving a receiving stone from that produced by moving a discharging stone. Referring to Fig. 74, it must be evident to the observer that the farther up that the locking takes place on the receiving stone the less will be the draft, and that the farther up it takes place on the locking face of the discharging stone the greater will be the draft.

In case the foregoing is not perfectly clear to the reader, let him suppose the tooth locked on the receiving stone at the junction of the lines, cc, and that a tooth dropped on the discharging stone, at the junction of the lines, ff. In this position the draft will be represented by the angle formed between the locking faces of the stones and the lines c and f, respectively. Now if—leaving the wheel tooth as it is— we draw out the receiving stone until its locking corner coincides with the junction of the lines aa, we have not changed the draft; but when the stone is thus drawn out the pallets will have to swing further to release the tooth, with the result that the lock will now take place on the discharging stone at the junction of the lines, dd. Thus it would be seen that the moving of a stone does not alter the draft on it, but on the opposite stone.

Lock.—Lock is the distance from the locking corner of a pallet stone to the point at which the wheel tooth strikes it at the instant it drops. It should be as little as possible, consistent with the proper allowance which should be made to cover certain unavoidable mechanical defects, such as side-shake in the pivot holes, inaccuracy in the escape wheel teeth, etc. The amount of lock measured in angular distance is about three-quarters of a degree. In actual measurement, it would be, on a 16 or 18 size escapement, 2 to 3 hundredths of a millimeter.
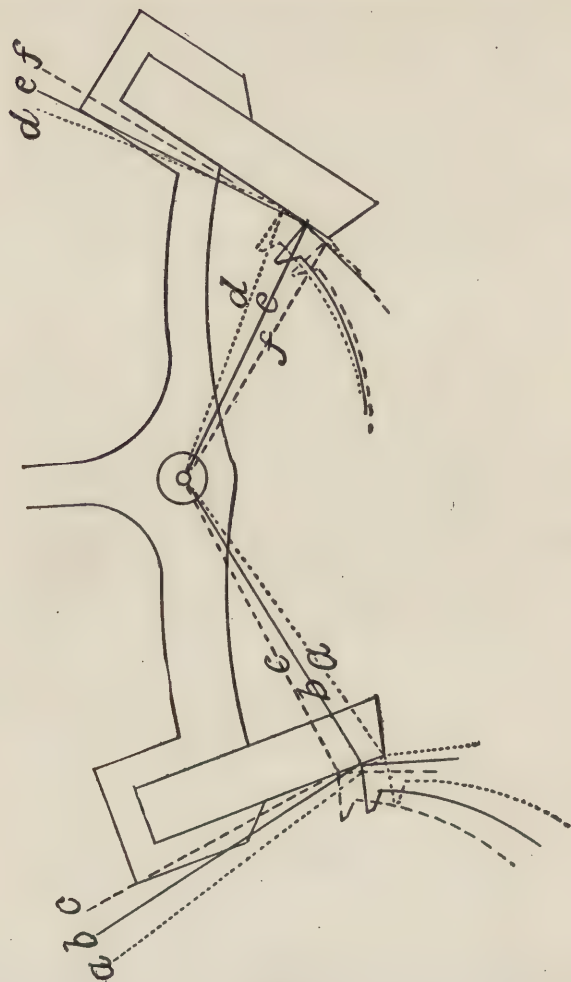
Fig. 74.

Fig. 75 will give an idea of this amount in proportion to the size of the escapement.

Moving one pallet stone, either outward or inward, alters the lock on both stones. While it does not alter them

exactly in the same proportion, yet the difference is trifling for ordinary alterations of this nature. In equi-distant center escapements, when the lock is equal as to angular measurement, it will be slightly greater in actual measure-
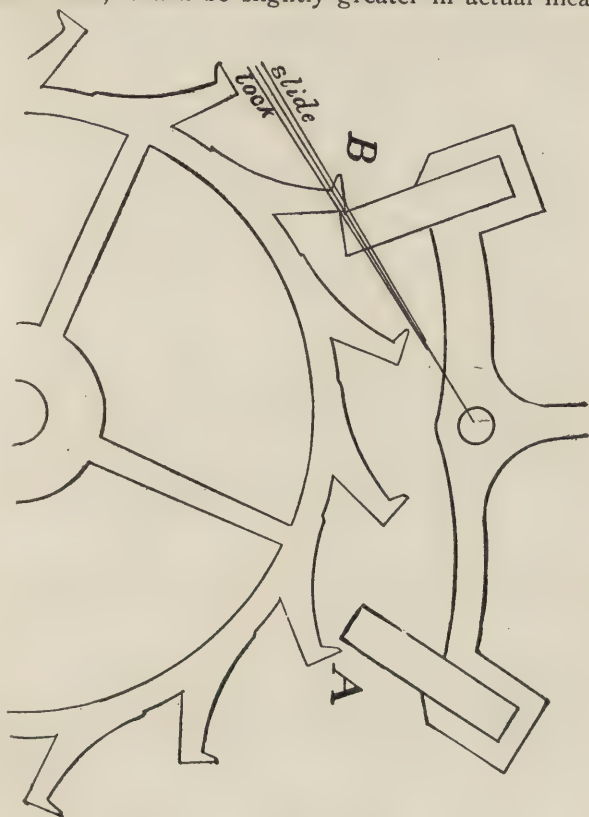

Fig. 75.

ment on the receiving stone than on the discharger. This is due to the fact that the locking face of the receiving stone is farther from the center of the pallet than the locking face of the discharging stone from the same point. Judgment should be used when making an alteration for lock. Bear

in mind what has been said in reference to the effect, in other particulars, of moving a stone.

SLIDE.—Slide—sometimes called run—is the distance from the point at which the wheel tooth strikes the locking face of a stone at the instant of drop to the point it reaches when the motion of the pallet is arrested by the fork coming in contact with the banking. The purpose of the slide is to allow proper freedom for the impulse pin to pass out of the fork slot; also, freedom between the guard pin and the edge of the roller. Its amount should be about the same as the lock. Fig. 75 shows both lock and slide on the receiving stone as indicated by the lines radiating from the pallet center.

Lock and slide, in combination, are sometimes called "total lock." This term seems confusing as it necessitates the use of the two terms, "lock" and "total lock." It leads to a confusion of terms. Lock and slide are two distinct functions. Opening or closing a banking alters the slide, but does not change the lock. A pallet stone must be moved to change the lock.

Referring back to Fig. 53 it will be seen that a wheel tooth is locked on the receiving stone, but the fork is not quite in contact with the left banking. Moving it into contact will make the slide on the stone. The slide is very easily changed by moving the banking, but should never be increased beyond an amount equaling the correct lock.

DROP.—Drop is the space that the escape wheel passes through during the interval between the release of one tooth by a pallet stone and the arrest of another tooth by the opposite stone. The drop is clearly shown in Fig. 75. At the point marked A, the tooth has just been released by the discharging stone; at B, a tooth has contacted with the locking face of the receiving stone. The space intervening between the releasing corners of tooth and stone

at A, exactly equals the space between the locking corner
of the tooth and its point of contact with the stone at B
before it dropped. This is the drop and should be alike
on both stones.

Drop may be altered by spreading the stones apart or
closing them together. The former increases the drop from
the receiving stone to the discharger and decreases the drop
from the discharger to the receiver. Closing the stones has
the opposite effect; hence it is seen that a change made in
this manner may affect a correction with a very slight
movement, as its effect is always multiplied by two. There
is another way in which the drop may be altered, which
is by moving a pallet stone in or out. Moving a pallet
stone does not change the drop on that stone, but on the
opposite one.

Moving the receiver out increases the drop on the dis-
charger; moving the discharger out increases it on the
receiver; moving it in has the opposite effect.

Drop is sometimes termed inside and outside shake,
meaning that when a tooth has been released by the dis-
charging stone and another locked on the receiving, if the
pallets are then swung so as to almost—not quite—lock,
the wheel may be moved to and fro. The locking corner
arrested by the receiving stone and the releasing corner of
another tooth arrested by the discharging stone. This is
called the outside shake. With a tooth just locked on the
discharging stone there will be three teeth embraced by the
stones and the play between them is called the inside shake.

Figure 73 will illustrate what is meant by inside and out-
side shake. In both A and B, the escapement in full lines
shows the outside shake; that in dotted lines the inside
shake. At A, the lock is equal and the inside and outside
shakes are equal, while at B, the locks are unequal making
the outside shake close. In speaking of shake, as applied
to pallets, it is technically termed "close inside" and "close
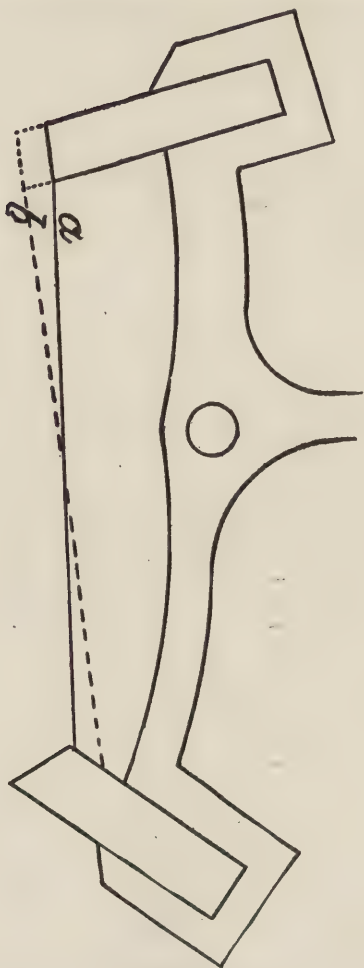outside," the former meaning that the drop is less on the

Fig. 76.

discharging stone; the latter, that it is less on the receiver.

The effect upon the drop—shake—of moving a pallet stone is clearly demonstrated by figures 76 and 77. In Fig. 76, the full line, a, gives the distance that embraces three

escape wheel teeth when the escapement is properly locked on the discharging stone. The broken line, b, gives the distance when the receiving stone has been drawn out to the position shown in dotted lines. This proves that drawing out the receiving stone increases the inside shake. Fig. 77 shows the effect of drawing out the discharging stone, which decreases the outside shake, but not to so great an extent as the effect of moving the receiving stone.

EQUI-DISTANT LOCKING AND EQUI-DISTANT CENTER ESCAPEMENT.—It is well that the student should inform himself as to the precise meaning of the above terms and the different conditions they produce.

They apply solely to the pallet.

Any usual form of escape wheel teeth may be used; in fact all usual forms of wheels and forks indiscriminately.

Fig. 78 shows both forms. At A, is shown equi-distant locking. The locking corners of both stones are at equal distances from the center of the pallet, as indicated by the full circular line. This feature gives the escapement its name. The releasing corner of the receiving stone is nearer the center by the distance between the broken and full circle. The releasing corner of the discharging stone is farther from the center by the distance between the dotted and the full line circle; thus it will be seen that, while the locking corners are equi-distant, the releasing corners differ in distance by double the width of the stone.

At B, is shown the equi-distant center escapement. In this drawing two full circular lines are drawn from the pallet center. The locking corner of the receiving stone and the releasing corner of the discharging stone are at equal distances from the pallet center. The same is the case with the locking corner of the discharging stone and the releasing corner of the receiving. This brings the centers of the impulse faces equi-distant from the pallet center, which gives this escapement its name.
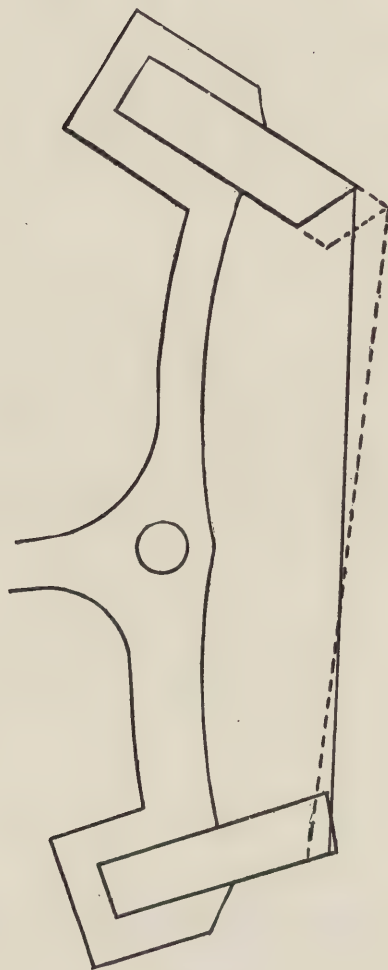
Fig. 77.

As has been explained, the lift—the angular impulse—is measured from the pallet center. It is shown at A, as indicated by lines embracing the angles, 1 and 2. It will be noticed that the impulse face of the discharging stone, forms a greater angle with its locking face than the impulse face of the receiving stone does with its locking face. At B, the angles 3 and 4, determining the impulse angles
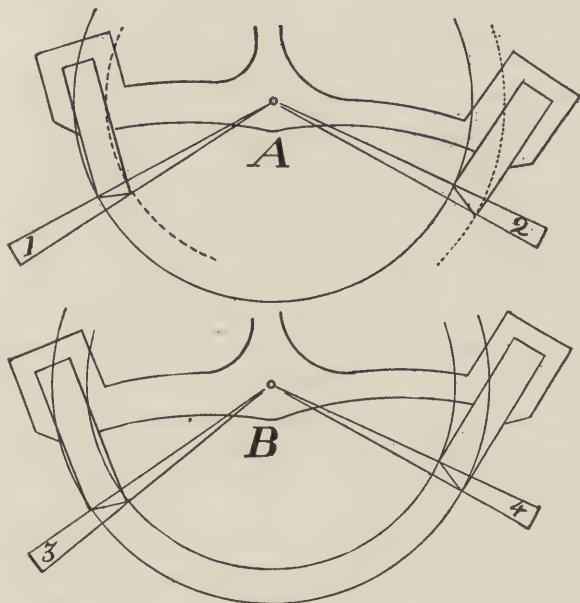

Fig. 78.

of the stone, are the same as 1 and 2, but in this case the impulse faces form equal angles with the locking faces.

There is another feature in connection with these escapements, which is that in the equi-distant locking, the discharging stone must embrace a greater angle than the receiving. This peculiar feature will be demonstrated in the latter part of this work when the subject of drafting an escapement is taken up.

OTHER FORMS OF LEVER ESCAPEMENT.—The form of escapement under consideration thus far has been the club tooth, short impulse. The short and the long impulse are generally designated as the short and the long fork. So far as the extent of the impulse of the fork, the above term is not sufficiently definite. A long or a short fork can be constructed with either long or short impulse. When we come to consider the roller, however, the distance from its center to the impulse pin cannot be changed without altering the arc of impulse of the impulse pin.

Going back to Fig. 31, we find that the relative distance between the roller pin and the balance center, as compared with the distance from the pallet arbor to the fork slot, is as four and one-half to one, whereas in the short fork it is usually about three to one. The effect of this is that the impulse pin is in contact with the fork for a greater extent of the vibration of the balance in the long impulse —long fork—than in the short one. The short fork being usually about three times the length, it is in action with the roller pin about 30 degrees—three times the arc of vibration of the fork. In Fig. 31 it will be seen that the fork has an active impulse of 10 degrees and the roller 45 degrees.

In the first forms of detached lever escapements the active impulse was 10 or more degrees; sometimes as high as 12. This has been reduced from time to time until, in the modern escapement, it is usually found to be about eight and one-half. The roller impulse being 30 degrees, or even less. Reducing the arc of impulse makes it more difficult to secure the safety action of the guard pin on the single roller, hence the general adoption of the double roller.

The detached lever escapement owes its superiority to the fact that the balance performs so great a portion of its vibration free from contact with any other part of the mechanism. As has been said, in modern forms, the fork is only in contact for about 30 degrees. The shorter the duration of contact the better the rate secured. This, how-

ever, has its limit. We have been approaching the present form gradually and it would seem as though we had reached the limit. Further reduction would necessarily be secured only by a sacrifice of power, which, as already stated, is now very great. In Fig. 31 the broken diverging lines A A show the arc of impulse of the fork. Those marked B B, that of the roller.

THE POISED AND THE UNPOISED FORK.—For many years it was considered to be an important advantage to have the fork and pallets perfectly poised. In order to secure this it became necessary to add considerable weight to these parts. Fig. 31 illustrates a common form of counterpoise used on American watches. The Swiss usually use the fleur-de-lis pattern for a counterpoise, but whatever is used the adding of weight increases the resistance of inertia which the balance must overcome in unlocking the escapement. This is not compensated for by the questionable advantage of a poised fork.

A fork without counterpoise requires a slight increase in the draft angle. Mr. Grossman, in his prize essay on the lever escapement, gives 12 degrees draft angle for each stone. Doubtless, this would be enough for a poised fork, equi-distant locking, but it would not be safe for an unpoised fork, equi-distant center. This form of escapement should have 14 degrees for the discharging stone and 15 for the receiving stone.

It may be urged against the unpoised fork; that the additional draft increases the resistance—especially when the watch is in a vertical position with the fork horizontal. This is quite true so far as the lowermost stone is concerned. Assuming the fork points to the right, the resistance on the discharging stone would be increased, but it should be remembered that the resistance on the receiving stone would be decreased in exactly the same amount. Thus the mean of the two resistances would exactly equal the

resistance with the fork in a vertical position, either up or down.

Fig 79 illustrates the ratchet tooth escapement, which was the first form of detached lever to come into general use. This form of pallet was what is known as "close-pallet," in distinction from "exposed pallet." In the "close-pallet" the pallet arm is slotted longitudinally with its plane, while in the "exposed pallet" it is slotted transversely. The "close pallet" method is a more secure way of fastening the stone, but does not permit of alteration as readily as the "exposed
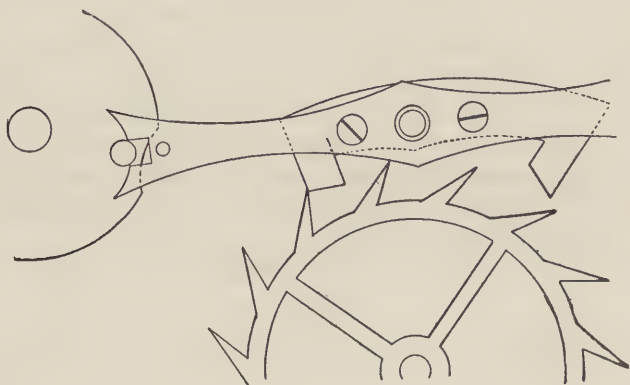
Fig. 79.

pallet." In the "close-pallet" the steel and the stone are finished flush on both locking and impulse faces which precludes the possibility of drawing out or pushing in either stone.

The escapement shown in Fig. 79 is what is known as the right angle escapement, which means that a line drawn from the center of the escape wheel to the center of the pallets and thence to the center of the balance, forms a right angle. All the early forms of levers were almost universally laid out on this plan; the inconvenience of having to locate the pallet arbor and the escape wheel under

the balance brought about the use of the straight line escapement, which is now the invariable form.

In the right angle-escapement, as shown in Fig. 79, the fork was attached to the pallets by two screws, the threads being in the pallet steel. The pallet arbor was fitted to the pallet steel, the hole in the fork through which it passed being a little larger. The holes in the fork for the screws permitted of adjusting the fork with the relation to the pallet, so that bending a fork was never necessary.
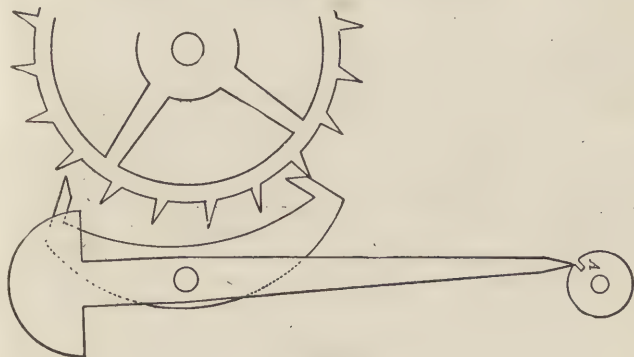
Fig. 80.

EVOLUTION OF THE LEVER ESCAPEMENT.—The evolution of the detached lever escapement is a most interesting history. It is but a little more than a century ago that the idea of transferring the motion from the escape wheel to the balance, by means of a lever was successfully applied.

Thomas Mudge, an English watchmaker, in 1765, was the first to produce a lever escapement. Fig. 80 illustrates his invention.

The pallets were so formed that the locking faces gave no draft, instead of which, they were inclined in the opposite direction, thus pressing the end of the lever against the roller. The roller was provided with a notch A into which the point of the fork entered in delivering its im-

pulse. No bankings were required in this escapement. Its great defect was the constant pressure of the fork against the edge of the roller. Reference to Fig. 80 will clearly illustrate this. The leverage exercised against the edge of the roller was of the same force as that to impart motion, and inasmuch as the pressure against the roller was at an acute angle with its periphery the retarding effect was great. If the reader will picture to his mind the effect of a guard pin continually pressed against the edge of a roller,
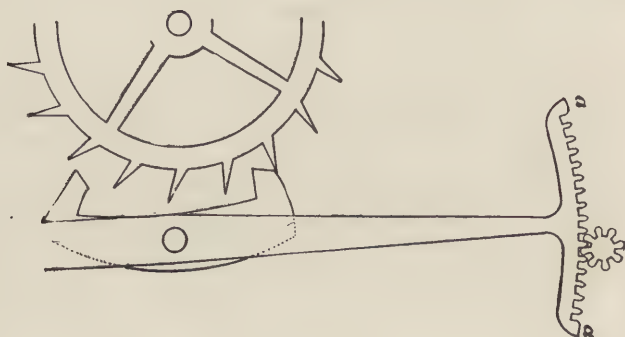

Fig. 81.

he can form an idea of this serious defect in the Mudge escapement. Increasing or decreasing the diameter of the roller in no way helped matters, for the reason that while decreasing the roller diameter decreased the resistance to the revolution of the balance, it also decreased the force of impulse of the fork. Increasing the diameter of the roller increased the force of the impulse, but also increased the resistance to the motion of the balance. In consequence of this radical defect, Mudge's escapement did not come into use; in fact, he did not adopt it in watches of his own production, using the cylinder and the duplex instead.

The next important step in development was the rack and pinion lever shown in Fig. 81. In this form the lower

part of the balance staff carried a small pinion into which
geared a circular rack on the end of the lever—the term
fork was not then used. The pallets were what is technic-
ally termed "dead beat," that is, they produced no recoil
to the escape wheel. The locking faces of both stones were
arcs of circles, the center of which was the pallet arbor.
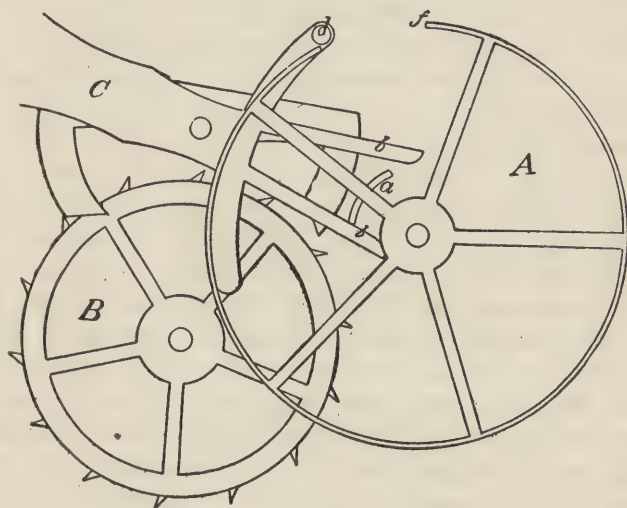The motion of the balance was limited by the toothless ends

Fig. 82.

of the rack, a a, which acted as bankings. When the rack
teeth and pinion leaves were properly proportioned and
well finished, this escapement gave fairly good results and
was in use many years. It was patented by Peter Lither-
land, in 1791, but is said to have been invented by Abbe
Hautefeuille, half a century prior.

Another form of escapement that came out about the
same time is shown in Fig. 82. This escapement was a
"dead beat." The escape teeth stood perpendicularly to the
plane of the wheel. The balance is not shown. The

annular wheel A is a part that performs the function of the roller in the modern lever watch. The short segment, a, attached to the under side of one of the arms takes the place of the roller-pin. The projecting arms, b b, include a space that acts as a fork slot. B is the escape wheel, C, the fork. The fork carries two circular arms in the end of one of which is a stud, d, which serves as a guard pin. This stud in connection with the annular rim, f, provides the safety device. Bankings are provided, but not shown. When the wheel is locked on the receiving pallet the guard pin is on the outside of the safety ring. When the impulse begins, as shown in Fig. 82, the guard pin is in position to enter the opening in the safety ring and pass to the inside thereof. Thus the pin, d, and rim, f, perform the function of the guard pin and safety roller. The fork and pallets required perfect poise, which accounts for the otherwise useless arm extending from the right side of the fork. Notwithstanding the fact that the locking faces of the pallets were so formed that they acted as a sort of break to prevent the movement of the fork while locked and that the fork and pallets were perfectly poised, still the guard pin must necessarily sometimes be thrown against the safety ring, and this being located so far from the center, the motion of the balance would be much retarded. It is a surprise to the writer that draft was not given to the pallets in order to overcome the weakness just spoken of; this, however, is the exact condition of the escapement made, being drawn to scale from the original. I am inclined to the opinion that this was the first attempt at making a *detached* lever escapement. As will be seen, it was exactly the reverse of the double roller. In the escapement shown in Fig. 82 the impulse was delivered nearer to the balance center than the safety action, while in the double roller the impulse is delivered farther from the center than the safety action.

Fig. 83 shows a form of escapement suggested by Per-ron, a French watchmaker. This form is also a detached lever and was probably the first detached lever made. The pallets consisted of two pins, the impulse being entirely on the teeth, which was a radical departure from anything heretofore done. Another novel feature was the inclina-
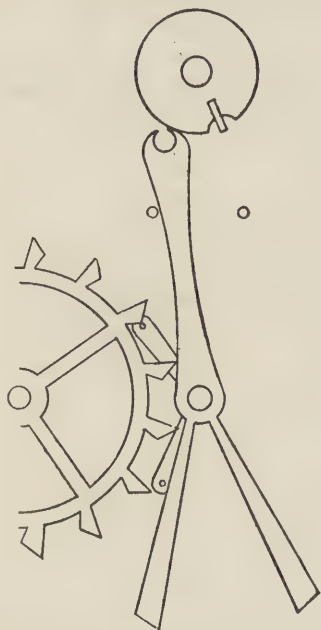

Fig. 83.

tion of the locking faces of the teeth, to draw the fork against its bankings. The safety action is performed by the outside of the horns of the fork and the roller edge. The impulse is delivered by a pin projecting radially from the roller. A passing hollow—the first device of the kind —permits the passage of the fork during the impulse.

Fig. 84 shows a form of fork and roller action called the crank lever, so called from its resemblance to the crank

of an engine. This form succeeded the rack and pinion and was in use for a long period. It had the advantage over the rack lever of being more simple to manufacture and to adjust. Like the Perron, the safety action was effected between the horns of the fork and the roller edge. The pallets and fork required a vibration of about 25 degrees and the roller about 70.

It has been thought that this form of fork and roller action may have been suggested by the rack and pinion for the reason that a resemblance may be traced to that form. If, in a rack and pinion, we cut off all but one leaf, and all

Fig. 84.

but two rack teeth, we shall have, virtually, a crank lever. The writer, however, is of the opinion that the semblance is more accidental than incidental.

The form of escapement shown in Fig. 79 was the standard for many years, being known as the detached lever. As other forms became popular, other terms were added to distinguish them apart, such as: Exposed pallets, Straight line, Club tooth, Double roller, Anchor, Equidistant centers, Equidistant lockings, Poised Fork, etc., many of which terms have ceased to be used.

A form of escapement that deserves special mention is shown in Fig. 85. It is the invention of a London watchmaker named Savage. Theoretically, this escapement embraces ideal conditions, especially in the unlocking and impulse. The unlocking is performed at a shorter radius from the roller center than the impulse is delivered. The
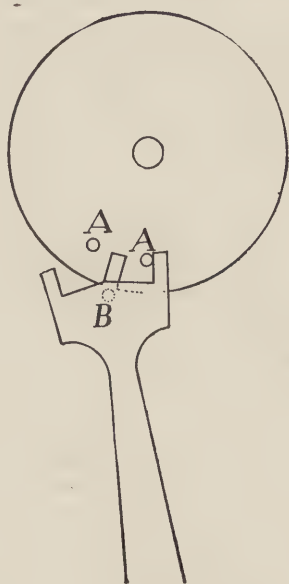

Fig. 85.

two pins A A, perform the unlocking, taking no part in the impulse. The pin B which is in the end of the fork performs the double office of impulse pin and guard pin. This form simplifies the production of a non-setting escapement, for the reason that both unlocking and impulse are performed under more favorable conditions than any other escapement of which the writer is aware. Its delicacy of adjustment, however, proved prohibitive to its general use.

CHAPTER V.

MAKING A DRAWING OF AN ESCAPEMENT.—It should be the aim of every watchmaker to acquire a theoretical as well as a practical knowledge of our craft. He should not be contented with the simple fact that making a certain alteration will produce a definite result, but should learn through what mechanical laws that result was brought about. With this knowledge he proceeds logically with his work. He applies the correct methods to remedy the defect; thus he accomplishes it in the shortest time and in the most workmanlike manner. Without this knowledge he works on the "cut and try" plan, and while he may eventually succeed in remedying the defect, it is often at the cost of valuable time wasted in futile attempts before success is achieved. This is particularly true of the lever escapement.

Making alterations in this escapement requires careful consideration and a thorough knowledge of its many functions, else in making a change to correct an error another and perhaps more serious error is likely to be created. As an adjunct to the attainment of this knowledge, making a drawing of an escapement is one of the best.

The purpose of this article is to give such instruction as will enable a workman, though he may not be a draftsman, to make such a drawing.

The student is recommended to take at least a few lessons in drafting. Where this is not convenient, the next best thing is to study some work on the subject.

All the tools necessary for a beginner are comprised in the following list:

A drawing board of any convenient size, say 20x26 inches.

One 18-inch straightedge.

One pair 6-inch compasses, with needle points, pencil, pen and lengthening bar.

One 3-inch spring-bow dividers.

One 3-inch spring-bow pencil.

One 3-inch spring-bow pen.

One 4½-inch ruling pen.

One bottle of waterproof drawing ink.

Two hard drawing pencils.

One rubber eraser.

One dozen thumb tacks.

One protractor.

In addition to these, a T square and two angles—a 45° and a 30°. These are not necessary, but are very convenient.

The object in using two pencils is that one may be sharpened to a chisel-shaped edge, the other to a sharp, round point.

A number of diagonal scales may be provided. Instructions for making these have been previously given in this series of articles.

A drawing enlarged to 40 diameters will be found convenient for an escapement, therefore make a diagonal scale to these dimensions. Place a piece of drawing paper of suitable size on the board.

Many of the lines necessary in laying out an escapement are solely for the purpose of locating the several parts that constitute the finished drawing. They are called "working lines."

In Fig. 86, as in the succeeding figures, these lines are broken. This is done in order that they may be engraved and printed readily, but the student may use pencil lines, which he can erase when they have served their purpose. Such of these as he may desire to remain should be inked

in red. Do not use an aniline red, for the reason that such lines fade out. Carmine does not fade.

Decide upon the center distances between the escape and pallets and the pallets and balance. In the following in-
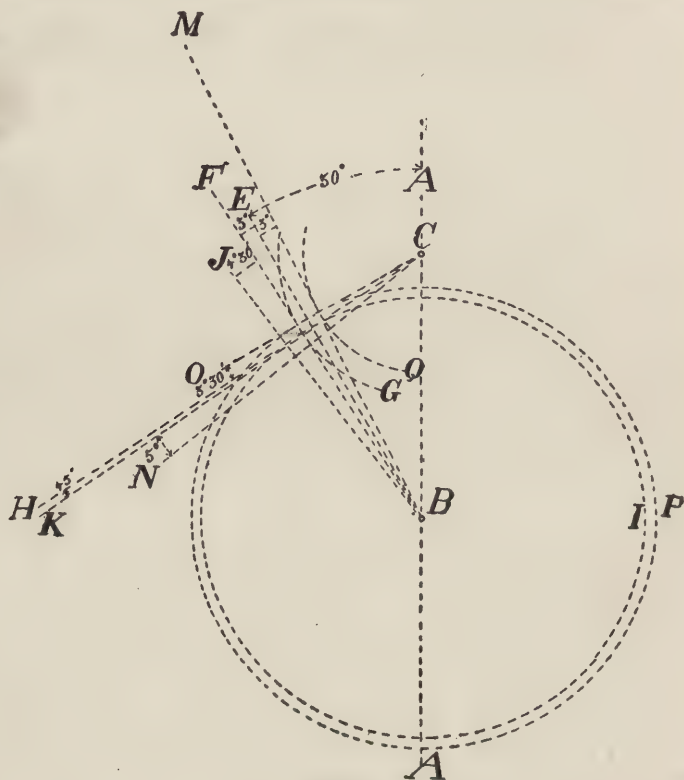

Fig. 86.

structions it will be understood that the measurements given are taken from the enlarged scale and not from the actual sizes:

Let us take 10 millimeters on our scale for the entire distance between the center of the escape wheel and the center of the balance.

The relative distances between the escape and the pallets centers and the pallets and balance centers may be taken at pleasure, provided it is within reasonable limits, say from escape center to pallets center, being anywhere between 30 per cent and 40 per cent of the entire distance between pallets and balance. These proportions are sometimes exceeded to accommodate other conditions, such as those existing in extra thin watches.

In this case we will take 3 millimeters for the distance from escape to pallets centers and 7 millimeters for the distance from pallets to balance center, making a total of 10 mm. Mark point B at a distance of about 3 mm. from one end of the line A. At a distance of 3 mm. from point B mark point C. B is the center of the escape wheel, C the center of the pallet. A is the line of centers.

The escapement may be drawn with its parts in any relative position to each other that they assume during action. In this case we will show them at the instant of locking on the receiving stone. In order to do this we must find the exact point of contact of the locking corner of an escape tooth with the locking face of the receiving stone. Before we do this, however, it is well, although not absolutely necessary, to decide what the circular impulse is to be and how it is to be proportioned between the wheel teeth and pallet stones.

The arc through which an escape tooth passes at each impulse is called the arc of impulse, and in an escape wheel of 15 teeth is 12 degrees. The reason that it must be 12 degrees is that each tooth delivers two impulses—one to the receiving stone and one to the discharging stone—during each revolution of the wheel. There being 15 teeth in the escape wheel, we divide the entire circle by twice that number, which gives us 12 degrees. This 12 degrees is not entirely taken up by impulse. A part of it is required for drop. In this case we will give 1½ degrees for drop. The remaining 10½ degrees is what is termed ac-

tive circular impulse and is divided between a pallet stone
and an escape wheel tooth. We will divide this active
circular impulse by giving 4½ degrees to the tooth and
6 degrees to the stone.

When the escape is locked on the receiving stone two
teeth stand between it and the locking face of the discharg-
ing stone. From the locking corner of a tooth to that of
the next adjacent tooth is 24 degrees, which is divided into
2 equal impulses of 12 degrees each. From the locking
corner of the tooth that is locked on the receiving stone to
the locking corner of the second tooth in advance is there-
fore 48 degrees. The third tooth, which has just been re-
leased by the discharging stone, is just one impulse—12
degrees—in advance, making an arc of 60 degrees in all
between the locking corners of the pallet stones when meas-
ured from the escape wheel center. In an equi-distant
locking escapement the locking corners embrace angles of
30 degrees at each side of the line of centers, but in an
equi-distant center escapement these 30-degree angles of
measurement pass through the centers of the stones, or, to
be exact, midway between where the paths of the locking
and releasing corners intersect like paths of the escape
teeth. This being the case, lines drawn from the escape
center 30 degrees each side of the line of centers will
pass through the centers of the stones; for this is to be
an equi-distant center escapement.

The foregoing has been gone into minutely in order that
the student may understand clearly why we use 30 degrees
from each side of the line of centers to determine the lo-
cation of the pallet stones. It must be understood, how-
ever, that this only applies to pallets spanning 2½ teeth of
a 15-tooth wheel.

Draw line E, 30 degrees to the left of the line of centers.
Inasmuch as this line runs through the center of the stone,
and that the locking corner is half the angle—6 degrees—

to the left of this point, draw a line, F, 3 degrees to the left of E.

The circular path of the receiving stone locking is tangential to this line. Its length is 1.63 mm. From C as a center draw an arc, G, with a radius of 1.63 mm. Draw line M, 3 degrees to the right of E. With dividers set at 2.52 mm. from B draw circle, I. This circle is called the primitive diameter of the escape wheel, and would be its diameter if the wheel was trimmed down to the locking corners.

Through the intersection of the circle I and the line E, from C draw line H. This line will form a right angle with line F.

The circular impulse, or rather that portion of it assigned to the wheel tooth, being 4½ degrees measured from the center B, draw line J that amount to the left of F. Upon this line will fall the releasing corner of the tooth.

We will now decide upon the amount of lock, which should be as light as possible, consistent with safety, say ¾ degree. From C draw line K, ¾ degree below H. Where this line intersects line F will mark the locking corner of the pallet stone.

We may now decide upon the arc of vibration of the fork and pallets. Let it be 10 degrees. Of this, ¾ degree will be for slide, ¾ degree for lock, leaving 8½ for active impulse—sometimes called lift. This amount should be divided between the tooth and stone in about the same proportion as the circular impulses bear to each other. We will give 5 degrees to the stone, 3½ degrees to the tooth. From C, 5 degrees below K, draw line N, and from the same center, 3½ degrees above line H, draw line O. From B as a center, through the intersection of lines M and O, draw circle, P. This circle will embrace the diameter of the escape wheel, over points.

At this point it may be well to give a simple rule whereby the true diameter of an escape wheel may be measured.

In spanning an escape wheel with a micrometer gage we do not get its true measurement, for the reason that the gage must necessarily bridge two teeth, which leaves us short of its true measurement by the height of the arc between these teeth. The process of measuring this accurately is somewhat complicated, but fortunately the writer has found a simple constant by which it can be closely approximated. To illustrate: Let us assume that the apparent diameter of the wheel is .300 mm.

$$\begin{array}{r} .300 \\ 300 \\ 300 \\ \hline .303300 \end{array}$$

This is the true diameter of the escape wheel.

From C as a center, through the intersection of circle P with line M, draw arc Q. This will be the path of the releasing corner of the stone.

The above embraces all the lines that it is considered well to put on the first figure. They are all working lines. The student cannot be too strongly urged to make himself familiar with the principles involved in locating these few lines, for they embody the fundamental principle of the lever escapement.

We shall now proceed with the instructions on another drawing. The student is to understand that he is not expected to make a separate drawing, but may do so if he chooses; otherwise he can simply add lines to the work previously done.

Fig. 87 illustrates the lines necessary for drawing the escape wheel.

Wherever a line or a point is referred to that appears on the previous drawing it will be found repeated on this one. For instance: Centers B and C, and lines F, J, O, H, and circles I and P are all transferred from the previous drawing.
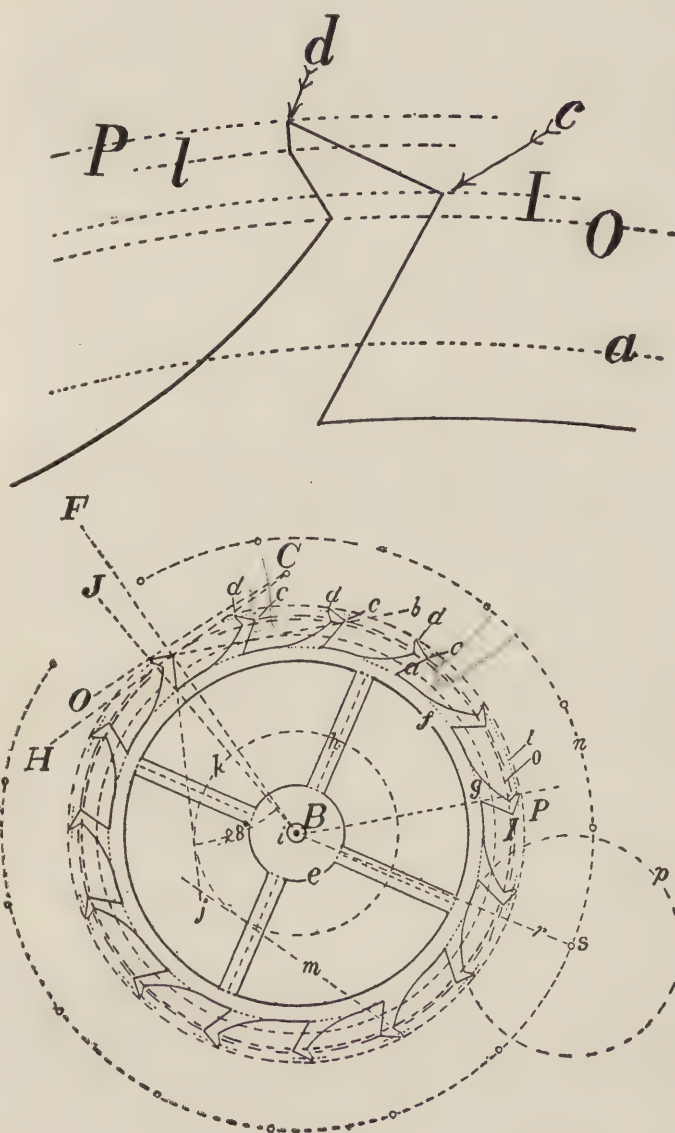
Fig. 87.

The impulse face of a tooth is formed by drawing a full line from the intersection of lines O and J to the intersection of lines H and F. Prolong this line to the right to b. From B as a center draw circle, a, tangential to line b. The radius of this is 2.30 mm. Its use is to aid in drawing the impulse faces of the other teeth.

From the locking corner of the impulse face just drawn in, mark off circle I into 15 equal spaces—c, c, etc. These will be the locking corners of the teeth. From these points with dividers set to the length of the impulse face already drawn in, mark points d, d, on circle P. These points will embrace the length of the impulses for the other teeth, being guided by the tangential circle a.

We will now draw the hub, arms and rim of the wheel. The dimensions of these are more or less a matter of taste. Taking the full radius of the wheel—2.66 mm.—as a basis, we will draw in the wheel to certain proportions, as follows: For the hub, 20 per cent. For the inside of the rim, 75 per cent. For the outside of the rim, 82 per cent. For the thickness of arms, 7 per cent.

Setting the dividers at 0.53, draw a circle, e, for the wheel hub. Setting at 2 mm., draw circle, f, for the inside of the rim. Setting at 2.18 mm., draw circle, g, for the outside of the rim. Draw four radial lines, h, at right angles to each other for the centers of the arms. With the dividers set at 0.09, draw the circle, i, and set off the same distance from the outer ends of lines h. With a straightedge, set at these points and tangent to circle i, draw in the edges of the arms.

The angle at which the locking face of the tooth should be formed may now be determined. This angle is frequently placed at 24 degrees from a radial line to the center of the wheel, but 28 degrees will be found better for the purpose, especially for an equidistant center escapement. The reasons for this are that an unpoised fork requires increased draft for the pallet stones, and with this increased

draft the locking face of the wheel tooth almost coincides with the locking face of the stone; furthermore, as the slide takes place on the discharging stone, the angle between the faces decreases, with the result that when the oil becomes viscid resistance is produced by adhesion. On the receiving stone, the greater the slide the more the divergence, but on the discharging stone, the greater the slide the less the divergence.

From the intersection of the lines H and F draw a line, j, forming an angle of 28 degrees with F. This is the locking angle of the wheel tooth. Draw circle, k, tangential with j. The radius of this circle will be 1.18 mm. It will be a guide for forming the locking faces of the other teeth.

From the points marked c, draw lines tangential to circle k. These will be the locking faces of the teeth.

Draw arcs, 1, just inside circle P. From the points marked d draw radial lines to the arcs, 1. These form the toes of the teeth. From the points where these lines touch the circle, I draw lines in a direction that would make them tangent with circle, k, as at m. These form the under side of the club.

The next step is to form the backs of the teeth. In doing this, care should be taken that they be so shaped that when the train of the watch is reversed they will not contact with the releasing corners of the pallet stones in such manner as to wedge the guard pin against the roller, a condition that is often found.

Draw a circle, n, 1.3 the radius of the wheel, which will be 3.46 mm. Now draw a circle, o, 95 per cent of the wheel radius, which will be 2.52 mm. With the dividers set at 1.28 mm., which is the difference between the radius of the circle, m, and the outside of the wheel rim, draw circle, p, from center, s, found on circle, n. An arc of this circle will form the back of a tooth. Draw similar arcs for the other teeth from similar points on the circle, n. These arcs begin at the points where lines, m, touch circle,

o, and end tangentially to the outside of the wheel rim. Line, r, connecting center, B, with center of circle, p, shows how the exact point of tangence with the outside of the rim may be determined.

This completes the directions for drawing the wheel, which may now be inked in as shown.

We will now proceed to draw the pallets, transferring, as before, such lines from Figs. 86 and 87 as are needed in making Fig. 88.

But four teeth of the escape wheel are shown in this drawing, being all that is necessary.

The circular impulse and the lift combined must be the same on both the receiving and the discharging sides. The circular impulse of the teeth is always the same, regardless of the position of the wheel. The circular impulse of the stones and the lift of the teeth must be modified according to location. As has been stated, the lift must be the same on both sides, but the proportions between the lift of the wheel and that of the stone vary considerably. This is a point we desire to direct especial attention to. It has been overlooked by some of our best authorities when writing on this subject; indeed, it is frequently found improperly depicted on escapement drawings.

Instructions would not be complete without a demonstration on this vital point. The first operation is to extend the arcs, G and Q, Fig. 88.

The points from which the circular impulse of the discharging stone is determined are the intersections of arc Q with circle I and of arc G with circle P, therefore draw lines R and S from B through these points. These lines embrace an angle of 6 degrees, as do lines F and M on the receiving side, and are the circular impulses of the stone.

The lift of the tooth is determined on the discharging side from the same intersections; therefore draw lines T and U from C through these points. It will be evident at

a glance that the lift of the tooth is greater at the discharging side than at the receiving side, the difference being about 1 degree.

Compare the angle included between H and O with that between T and U.

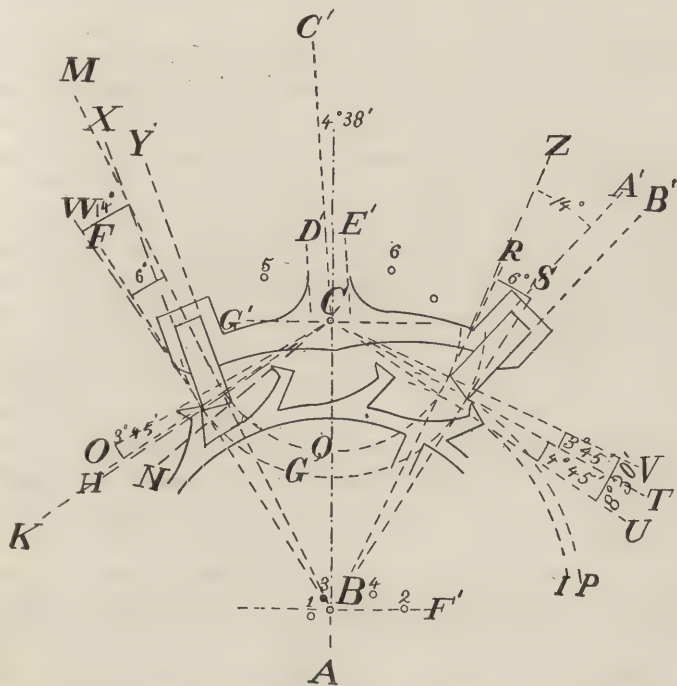The lift of the tooth at the discharging side being greater

Fig. 88.

than at the receiving side, it follows that, in order that the combined lift be alike on both sides, the lift of the stone must be less on the discharging side. At the discharging side the wheel lifts the pallets through an arc of 4¾ degrees; the lifting angle of the discharging stone therefore must be just enough to make up the difference between

that amount and 8½ degrees, which is the entire lift. This amount will be 3¾ degrees. From C draw line, V, 3¾ degrees to the left of T. Connect the two points of intersection: Q with V and G with T. This will give the impulse face of the discharging stone.

For the impulse face of the receiving stone connect the points of intersection of arc G with line K and with arc Q with line N.

The student who desires to acquaint himself thoroughly with the principles involved in this most intricate of all escapements should carefully note the points referred to above. At the risk of unnecessary repetition we will explain again, minutely.

The action of an escape wheel tooth in oscillating a pair of pallets drives them through an arc of a circle the angular extent of which is measured by radial lines from the pallet center. The angle formed by these lines is called the lift. The lift given in the drawing under consideration is 8½ degrees, exclusive of the lock—the lock being no part of the *active* impulse. The lines that measure the lift of the pallets pass, one through the locking corner, the other through the releasing corner of each stone, the angles formed thereby being identical, regardless of the changing position of the pallet.

Radial lines from the pallet center also measure the lift of the wheel tooth. These lines pass, one through the locking corner, the other through the releasing corner of the wheel tooth. There is this difference, however, between the two conditions: the locking and releasing corners of the stones do not change their relation to the center from which the lift is measured, while the locking and releasing corners of the wheel teeth are constantly changing their relation to the center from which their lift is measured.

This being the case, the manner in which the lifting angle of a tooth is measured is to draw one line from the center of the pallets through the locking corner of an es-

cape tooth at the point where the lift begins and another where the lift ends, the embraced angle being the lift of the wheel tooth.

We will now determine the angle at which the locking faces of the stones should be drawn. They should be at such an inclination that the pressure of the wheel teeth will bring the fork to its bankings, holding it there until released by the action of the roller pin. This is called the draft or draw. Its force is determined by the angle that the locking face forms with a line at right angles to a radial line from the pallet center to the locking corner of the stone. K is such a radial line, W is a line at right angle and X is the line upon which the locking face of the stone should be drawn.

From the locking corner of the receiving stone draw line W at right angles with K. From the same point draw line X at the right of, and 14 degrees from W. From the releasing corner draw line Y parallel with X. This will give the form of the receiving stone.

From the locking corner of the discharging stone draw line Z at right angles with V and from the same point, line A' 14 degrees from Z. From the releasing corner draw line B' parallel with A'. This will give the form of the discharging stone.

Instead of drawing line W to take the angular measurement from, it may be taken directly from line K, the angle being 76 degrees. The complement of an angle is the difference between that angle and 90 degrees. Now inasmuch as W forms an angle of 90 degrees with K, and we wish to draw a line 14 degrees less, if we draw it 76 degrees from K it will amount to the same thing.

The form of the pallet steels is to a large extent a matter of taste. Lightness of structure, however, is to be aimed at. Another condition that plays an important part is to have the arms of the pallets as near the wheel as possible in order that they may act, to some extent, as a

counterpoise to the fork. The lower part of the fork, only, is represented in this drawing. It should be borne in mind that the fork as shown is at half its arc of vibration to the left of the line of centers, therefore, from the pallet center C, draw the line C' at an angle of 4 degrees 38 minutes from the line of centers. Draw two lines D' and E' .15 mm. at each side and parallel with C'.

The amount of steel surrounding the stones may be about .15 mm. The position of the lines forming the steels do not call for lettering, but the means of locating them will be defined. The arms being formed of arcs of circles, their centers must be located. For this purpose four centers, numbered 1 to 6, inclusive, are found.

The method of locating the points referred to above is that pursued in laying out a watch model. In laying out a watch model two lines are drawn, one through the center and fourth holes, called the north and south line; another through the center, at right angles with the north and south line, this being called the east and west line. In locating the points for this drawing the line of centers, A, Fig. 88, will be the north and south line. A line F' drawn through the center of B will be the east and west line for points 1 to 4 inclusive. A line G' will be the east and west line for points 5 and 6. It will be understood that when we say a point is north or south it will be north or south of the east and west line and when it is said to be east or west it means that it is east or west of the north and south lines.

Arcs of 2.80 mm. radius are described from 1 and 2 to form the belly of the pallets. Arcs of 2.95 mm. from 3 and 4 form the back of the pallet. Point 1 is .10 mm. south and .22 mm. west. Point 2; being directly on the east and west line, is simply specified as .88 mm. east. Point 3 is .10 mm. north and .10 mm. west. Point 4 is .15 mm. north and .45 mm. east. Point 5 is .47 mm. north and .73 mm. west. Point 6 is .55 mm. north and .63 mm. east.

Draw arcs of circles from points 1 and 2 of a radius of

2.80 mm. to form the belly of the pallet. Draw arcs from points 3 and 4, radius 2.95 mm. to form the back of the pallet. To form the circles that connect the pallets with the fork two arcs of circles are drawn each with a radius of .47 mm.

This completes the pallets.

FORK AND ROLLER.—We will now proceed to lay out the fork and roller. (See Fig. 89.) The first point to be decided is the proportional distance of the impulse pin. On this will depend what is usually termed the freedom of the escapement. The proportional distances of the impulse pin and the fork slot from the centers upon which they vibrate is a highly important matter for consideration. The farther the impulse pin is from the center of the balance, the greater the force delivered by the fork, and the shorter the arc of contact; but as the force delivered by the fork to the impulse pin is increased by decreasing the length of the fork, the force delivered by the impulse pin in unlocking is decreased.

In view of the above condition it only remains for us to seek a "happy medium."

When a balance is stopped with the impulse pin on the line of centers and then released carefully, the watch should start even when the power is light—at the end of a 24 hour run. When a watch does not start under these conditions it is said to "set on the impulse." When a watch, wound to the top will not start when the balance is drawn to a position with the wheel tooth on the locking face, almost ready to unlock it is said to set on the locking. This condition will be found when the fork is too short in proportion to the roller. An escapement that is free from these conditions is said to be a free—live—escapement. To avoid one or the other of these conditions it is necessary to have the distances properly proportioned to each other.

We will make them 3 to 1; 3 for the fork, 1 for the roller
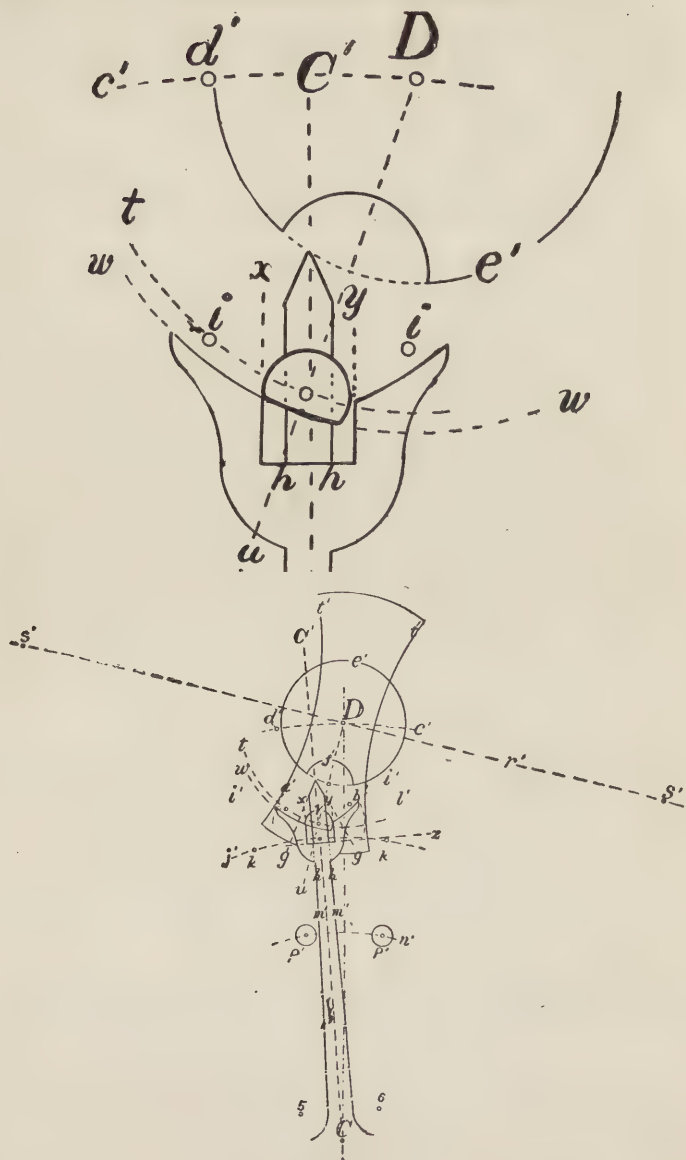
Fig. 89.

pin. With the dividers set at 1.75 mm., draw the arc of the circle t from D as a center. From D through the intersection of line C' and arc t, which is the center of the jewel pin, draw line u. For the size of the impulse pin divide the center distance—10 mm., by 21, which will give .476 mm. This is the diameter of the impulse pin. Setting the dividers at .24, from the intersection of line u with arc t, draw the circle v. This will be the impulse pin. The face of the impulse pin should cut it off to about two-thirds. With the dividers set at 1.83 mm., draw the arc w. This arc will give the face of the impulse pin. The face should be the arc of this circle instead of being flat, as is often seen. In the single roller a flat faced pin is not seriously objectionable, but in the double roller it is of importance that it be circular. The reason for this is that a considerable portion of the safety action comes between the face of the impulse pin and the circle of the fork horn; hence, the resistance should be reduced to the minimum and the action made as smooth as possible. Draw the lines x and y parallel to C' and tangent to the impulse pin. These will give the sides of the fork slot. For the bottom of the fork slot draw the line z .32 mm. from the center of the impulse pin.

The fork horns should extend at each side of the slot to a distance at least equaling its width. Setting the dividers at .78 mm., draw two short arcs, a' and b', from the center of the slot. The inside curves of the fork horns will end at these arcs.

The curves of the fork horns should be arcs of circles of the same radius, but not from the same center. In the position in which the fork is shown, the arc which forms the left horn is from the roller center and corresponds with arc w. To find the center for the curve of the right horn draw arc c' from C as a center and through D. On this arc, to the left of its intersection with C', mark point d' at a distance equal to that from the intersection to D. The

point d′ will be the center from which to draw the curve of the right fork horn.

The radius of the safety roller is usually two-thirds the distance from the roller center to the impulse pin center. With the dividers set at 1.17 mm., draw the circle e′. This will be the safety roller.

The passing hollow may be of generous dimensions, for the reason that the fork horns, when made as directed, provide additional safety against the fork going out of action. With the dividers set at .40 mm., draw arc f′ from a center at the intersection of line u with circle e′. This will be the passing hollow.

The guard pin—sometimes called the dart—should be drawn with its point at the intersection of line C′ with circle e′. From this point draw lines g′, at each side of and 25 degrees from the line C′. These will form the point of the guard pin. At each side of, and parallel to the line C′, draw the lines h′. These lines may be half the diameter of the impulse pin apart. They will form the sides of the guard pin.

The form of the fork is largely a matter of taste, lightness being a desirable feature.

Setting the dividers at .63 mm., mark the point i′, on the arc t. Mark a similar point to the right. From these points, with the dividers set at .15 mm., draw arcs of circles to form the ends of the horns as shown. These arcs are not lettered, but the student will have no difficulty in distinguishing them. From C, with the dividers set at 5.10 mm., draw the arc j′. From the intersection of this arc with C′, with the dividers set at 1.18 mm., mark the points kk. These points are the centers from which to draw arcs tangential to those forming the ends of the horns, thus forming the sides. From the point l′ as a center, draw an arc tangential to those forming the sides of the fork. This arc will complete the fork end. With the dividers set at

.14 mm., mark points on this last arc from its intersection with C', and from these points draw the lines m' and m'' connecting with the arcs formed from points 5 and 6. This finishes the fork.

The location of the banking pins, so far as their distance from the pallet center is concerned, is a matter of no vital importance. The best position would be the points which would arrest the fork by contacting with it at its center of percussion. It is rarely, however, that circumstances will permit of this. We shall locate them in about the usual place. With the dividers set at 3.50 mm., from C draw the arc n'. Set the dividers at .65 mm. and mark the points p' from the intersection of the arc n' with the line of centers A. These will be the centers of the bankings. In drawing the bankings it should be borne in mind that the pallets as shown are just at the locking point, the slide not having taken place, consequently the fork should not be represented in contact with a banking; therefore draw them as shown, leaving a space between.

The piece which carries the impulse pin is generally made in the form of a disc and is called the impulse roller, but it may be made in the form of a bar and termed the impulse bar, which is the form which has been adopted in this drawing. Draw the line r', through the center D, at right angles with the line u. On this line, 5.56 mm. on each side of the center of the roller, mark the points s'. Setting the dividers at 5 mm., from the points s', draw the arcs t' to form the sides of the impulse bar. This will complete the entire escapement.

If the student has used a sharp, hard pencil for the working lines and drawn them lightly, they may now be erased. In case it is desired to keep the drawing for use as a reference, the working lines may be drawn in red—carmine ink should be used for this purpose as it does not fade; while aniline ink does. When he has completed this draw-
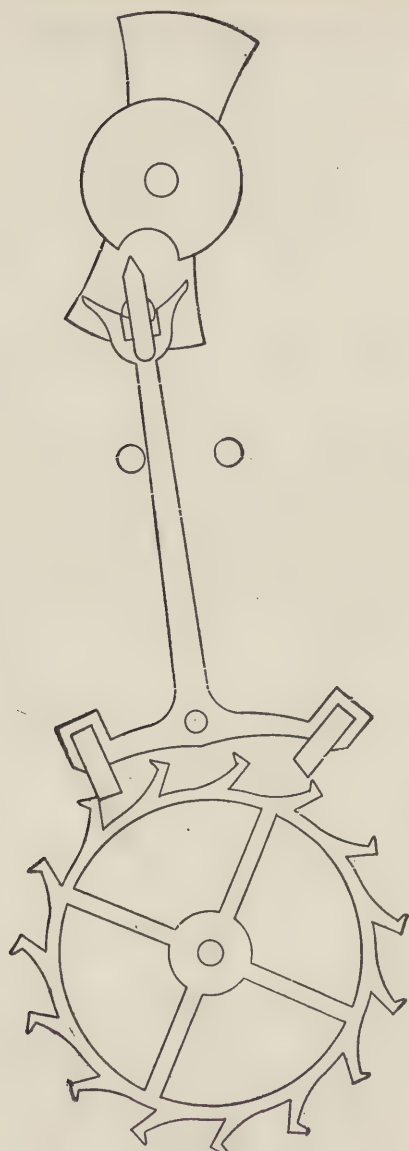
Fig. 90.

ing he will find himself equipped to make a drawing of any other form of escapement.

Fig. 90 shows the escapement divested of the working lines. For the sake of clearness, the rollers are shown bottom side up—the reverse of their position in the watch.

CHAPTER VI.

THE CYLINDER ESCAPEMENT.—The cylinder escapement was invented by George Graham in 1720.

It met with little favor at first, being condemned by most of the celebrated watchmakers of that time, among whom was Berthoud, who actually attempted to demonstrate that the verge escapement was much its superior.

It is a dead beat escapement which is, of course, a point in its favor. This point, however, is more than offset by
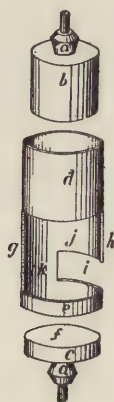
Fig. 91.

the fact that the escape tooth is in constant contact with the cylinder, and at a considerable distance from the center.

Fig. 91 is a perspective view of the cylinder and its plugs. The letters indicate the names applied to the different parts: a, the arbors; b, the great, or top plug; c, the small, or bottom, plug; d, the great shell; e, the small shell; f, the plug face; g, the receiving lip; h, the discharging lip;

i, the banking slot; j, the half shell; k, the cylinder column.

Fig. 92 is designed to show the action of the escape tooth on the cylinder. The names applied to the different parts of the teeth are: a, the top, or flat of the tooth; b, the impulse face; c, the arm of the tooth; d, the locking point; e, the heel; f, the space. That part of the tooth connecting it with its arm is not shown. It is called the column.

Six positions of the cylinder in action are shown, the cylinder moving as indicated by arrows. At A, the locking point of the tooth is in contact with the half-shell. At B, the tooth is about to unlock. At C, the face of the tooth is
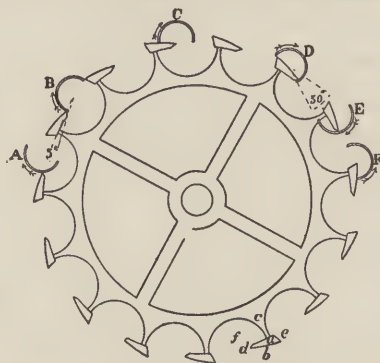
Fig. 92.

delivering an impulse on the receiving lip of the cylinder. At D, the impulse has been delivered and the tooth is in contact at the locking point with the inside of the half-shell. At E, the tooth is still in contact with the inside of the half-shell, the cylinder having revolved until the tooth arm has entered the banking slot. The purpose of this slot is to allow the balance a wider arc of vibration than if it was not introduced into the half-shell. At F, the motion of the cylinder has reversed, the tooth has been released and is delivering an impulse to the discharging lip of the cylinder.

The impulse faces shown in the drawing are slightly

curved, but they are more frequently to be found formed of a straight plane. There is some difference of opinion as to the best form.

When a curve is used it can be so formed that equal proportions of its length cause the cylinder to rotate through equal arcs, or it may be so formed that an equal resistance to the changing force of the hairspring is offered throughout the entire impulse. The straight face, however, causes the balance to give the greatest arc of vibration.

A condition brought about by the action of the escapement is that the size of the balance   as well as its weight, is confined to comparatively narrow limits. When the balance is heavier than these limits the watch loses with an increase of the motive force, and when the balance is too small it gains. This seems to conflict with mechanical laws, but is nevertheless a fact.

There is no other escapement, to the writer's knowledge, that requires more frequent cleaning. If this is not properly attended to, any approach to a steady rate is not to be expected. Owing to the peculiar shape of the teeth and their constant contact with the cylinder, dirt and thick oil will quickly accumulate on the parts, shortening the arcs of vibration of the balance.

The arc that the cylinder describes during the delivery of an impulse by an escape tooth is called "the lift." This is usually about 30 degrees, as shown at D, Fig. 92. The aperture in the cylinder shell is generally about 180 degrees. The thickness of the shell is about 1-16 the length of the impulse face of the tooth. The drop should be as small as possible, consistent with freedom. The smallest drop practical for a lever escapement is 1½ degrees, in the cylinder escapement it need not exceed 1 degree.

The amount of lock of the tooth on the cylinder shell should be 3 degrees, as shown at B, Fig. 92.

Le Roy says that the point of the tooth in its progress

should pass through the axis of the cylinder. Berthoud says that the middle of the locking face should pass through the axis. The writer favors the latter, but in other respects the rules laid down by Berthoud, for the construction of the cylinder escapement are not to be recommended.

When this escapement was first introduced the escape wheels were of brass, and, as might be expected, gave poor results. Later on, when steel wheels were adopted and the parts were highly finished, the time-keeping qualities were much improved.

There has been a great diversity of opinion on the part of experts as to the proportions of the parts, forms of curves, extent of angles, etc. Tavan, Moinet, Wagner, Robert, Jodin, Lepaute, Berthoud and Jurgensen, all eminent watchmakers, differ widely on many points; but inasmuch as no good purpose would be served by going minutely into details, particularly as the escapement is fast falling into disuse, their various opinions and arguments will not be discussed here.

There are two important matters to be observed in fitting a new cylinder: see that the depth between the cylinder and the escape wheel is so pitched that the center of the impulse face of the tooth passes through the axis of the cylinder. If the depth is too deep or too shallow, the friction of the tooth on the cylinder is increased, besides which the drop will not be equal. See that the drop is equal on the inside and the outside of the shell.

To sum up, the cylinder has in its time given good results, and should be appreciated from the fact that it filled the gap in a most satisfactory manner between the old verge and the detached lever. Indeed, Mudge, the inventor of the lever, preferred the cylinder to it, and used it in his own watches.

It must not be inferred that the cylinder in its best days made any approach in performance to the detached lever of

today.   Mudge's lever would hardly be recognized when compared with the modern lever escapement.

The cylinder escapement has degenerated into a poorly executed counterfeit of what it was in its palmy days, when the shell was a ruby and the other parts beautifully executed.   Add to this the fact that many of the escape wheels of cylinders as now made up have but six leaves, and it will be readily understood why it has fallen into disrepute.

An improperly designed or executed cylinder escapement can only be improved to a limited extent.   No amount of manipulation will make it perfect.

Watches having this escapement are usually provided with an adjustable potence which contains the lower jewels and carries the steady pin holes for the balance cock.   This enables an adjustment to be made for the depth of the cylinder into the escape wheel teeth.   Any other alteration is at best a makeshift

The description already given will enable the repairer to know when a cylinder escapement is correct.   To test its action move the balance slowly in either direction until the drop takes place.   Now reverse the motion a slight amount, just enough to insure a lock, and try the shake of the wheel on the cylinder.   Repeat this on the other lip and again try the shake.   It should be equal.   If it is not it indicates that either the wheel tooth or the cylinder, or possibly both, are not of correct size.   If the inside shake—the shake when the tooth is resting against the inside of the shell—is the greatest, it indicates that the cylinder is too large in diameter.   If the outside is the greatest, it is too small.   The correct way to remedy this is to put in a new cylinder of proper size.

In fitting a new cylinder, see that the shake is equal.

Additional instructions will be given when the repair of watches is treated of.

THE VERGE ESCAPEMENT.—The verge escapement is so

rarely found in use at the present day that only an exceedingly brief description of it is deemed necessary.

This escapement first came into use in clocks in the early part of the 14th century, not being applied to watches until some time later. It continued to be used in watches to a constantly diminishing extent until about half a century ago, when it ceased altogether.

Figure 93 illustrates the form and action of the verge escapement. Tooth, a, is delivering an impulse to the pallet, a′, driving the balance in the direction indicated by an arrow. This tooth moves to the right, also indicated by an arrow. Tooth c is moving to the left, as indicated. When

Fig. 93.

tooth a is released, tooth c will drop on the pallet c′ and deliver an impulse in the opposite direction.

It is evident that this escapement has an excessive amount of recoil, hence its unreliability. Even a slight variation in the power produces a material rate error, so that under the most favorable conditions it is unreliable. The wearing of the parts which in this escapement is always very great soon causes the watch to gain on its rate, and as the balance, or rather verge, is seldom jeweled this wear soon makes itself manifest.

Another part of the escapement which soon becomes deranged is the escape wheel teeth. These not only wear away, but do so very unevenly, leaving them of varying

length; in fact, this is one of the most common defects to be found in an old verge watch. It can be remedied by the process known as "topping and filing." The usual method of doing this is to fasten a screw collet to the escape staff and, using a Swiss Jacot lathe, or an English pivot lathe and a fiddle-bow, true the teeth to length with a slip of blue-stone, or water of Ayr stone.

The stone should be held firmly against the T rest and brought carefully forward until the longest tooth touches it. Then proceed carefully until all the teeth are of an equal length. Using oil on the stone has the effect of cutting without throwing a burr. After this operation the teeth should be dressed up on the back with a small, fine, half-round file (such a file as comes under the head of an escapement file). It may be found at any watch material dealers.

When the operation has been performed it will generally be found that the escape wheel does not engage deeply enough into the pallet, but in this escapement that trouble is easily corrected. The escape wheel in a verge watch usually has much more end shake than is necessary. It does no harm for the reason that the action of the escapement keeps the escape wheel constantly pressed away from the center of the verge. The outer pivot finds its bearing in what is called by the English "a follower," which is frictionally inserted into a hole and can be adjusted forward to bring the escape wheel teeth to the proper depth in the verge.

In Swiss watches, the same alteration can be made by moving forward the piece called "the counter-potence," which contains the bearing in Swiss verges.

THE DUPLEX ESCAPEMENT.—This escapement made its appearance about the middle of the eighteenth century. It was the invention of an ingenious French watchmaker—Dutertre—but was perfected by LeRoy. It acquired its name from the fact that in its original form it had two

escape wheels, hence the application of the Latin word, duplex—double.

The duplex escapement met with favor among the English watchmakers and was very popular for a considerable period.   In this connection it is a remarkable fact that
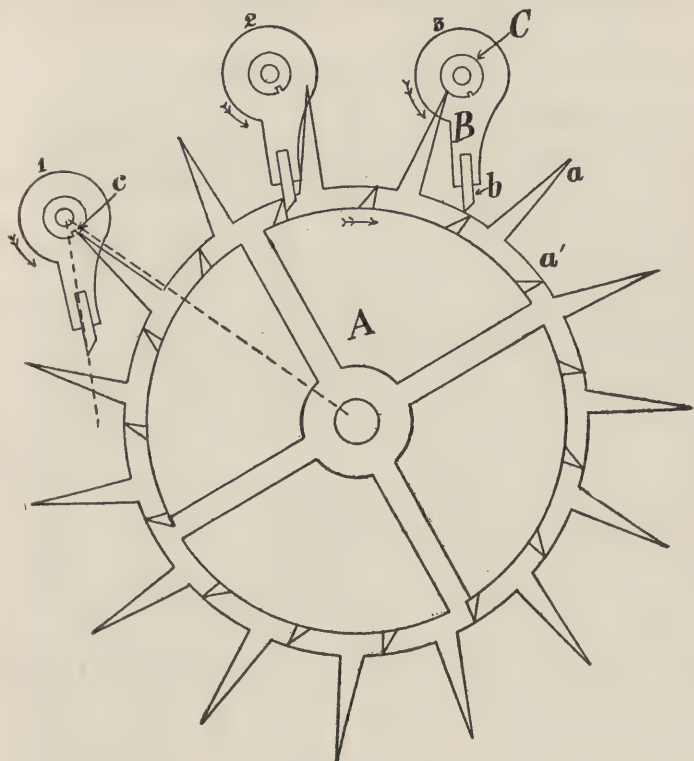
Fig. 94.

although a French invention it did not become popular in France; but the cylinder, an English invention, was extensively used there, and but very little used in England.

Fig. 94 illustrates the appearance and action of the duplex escapement.

A, the escape wheel.

a, the locking tooth; lying in the plane of the wheel.

a′, the impulse tooth; standing at right angles with the plane of the tooth.

B, the impulse arm, carried by the balance staff.

b, the impulse pallet.

C, the roller, carried by the balance staff.

c, the releasing slot.

The impulse arm is located above the roller. The roller is generally of ruby or sapphire, but is sometimes omitted, a slot in the staff taking its place.

The action of the escapement will be made clear by referring to Fig. 94, the parts being represented as moving in the direction indicated by the arrow. 1 shows a locking tooth about to enter the releasing slot in the roller. As the roller moves forward the tooth passes into the slot and is in turn released, thus allowing an impulse tooth to drop on the impulse pallet, as shown at 2. When the impulse tooth has delivered its impulse it is released and a locking tooth drops upon the roller, as shown at 3.

On the return excursion the locking tooth again enters the roller slot which allows the tooth to drop forward a slight amount, but not enough to release it, and it is immediately forced back to place against the outside of the roller. This exercises a slight retarding influence on the balance which, however, is compensated for when the roller moves in the opposite direction—the direction indicated by the arrow. When it drops into the slot under this condition it delivers a slight impulse, which is called "the lesser lift." The lift delivered by the impulse tooth is termed "the great lift."

The adjustment of the rollers to the proper angular relation to each other is of vital importance. The releasing slot must be so placed that it will release a tooth at exactly the

right instant. If the tooth is released too soon the impulse tooth will not engage the pallet, because the pallet will not have entered the path of the tooth, which will then go forward without delivering an impulse. If the tooth does not enter the slot soon enough, and its release is too long delayed, the impulse will be shortened and a poor motion will result.

In the drawing the parts are shown in correct position, but are not strictly correct from a draftsman's point of view, which would require some of the lines to be shown broken.

The duplex escapement requires extreme delicacy in its manufacture and adjustment; a wide side-shake, or other slight error being fatal to its proper action. There is comparatively little loss from drop, and it utilizes the movement of the wheel in delivering the impulse to fully as great an extent as in the lever. In the lever, however, the balance revolves without any restraint (except that imposed by the hairspring) except during the brief period that the unlocking and impulse are taking place, whereas in the duplex escapement there is continual contact between the escape wheels and the rollers. For the greater portion of the time a tooth is pressed against the edge of the roller at an extremely unfavorable direction—74 degrees from a right angle, or its complement, 16 degrees from a tangent.

A high authority on horology refers to the duplex as possessing a rate equal to the lever. This might have been true at the time the comparison was made—nearly half a century ago—but it is far from being the case at the present time. Those who have had much experience with the duplex will bear the writer out in this statement. The duplex is not manufactured at the present time, but many of them are still in use and come into the hands of the repairer; the watchmaker should therefore acquire a thorough knowledge of the principles of this escapement.

As in laying out the lever escapement, authorities differ to a greater or less extent as to the proportions that give

the best results in the duplex. Saunier in his excellent work, giving for his authority Jurgensen, says:

"The diameter of the roller should be a third of the distance between two adjacent locking teeth of the escape wheel.

"The lifting action on the roller—the small lift—extends over an arc of 20 degrees.

"The drop of the impulse tooth on the impulse pallet should be 10 degrees.

"The active impulse on the impulse pallet, measured from the center of the staff should be 30 degrees."

He quotes many authorities, all of whom, with one exception, agree upon the arc of impulse; the exception referred to is M. Winnerl, who gives the greater lift as 60 degrees, 15 of which is drop, leaving 45 degrees for active impulse.

The lift is determined to some extent by the proportions between the roller, impulse pallet and diameter of the escape wheel. For instance, authorities differ greatly as to the relative diameter of the roller as compared to the distance between the points of two teeth. Taking six of the principal manufacturers we have a maximum of two-fifths and a minimum of one-sixth.

THE CHRONOMETER ESCAPEMENT.—Next in importance to the lever is the chronometer or detached detent escapement. Its chief value consists in its adaptability to navigation.

The instrument known as the marine chronometer is capable of close rating when it is kept in a horizontal position and is specially adjusted therefor. It is invariably hung in gimbals which maintain it in a horizontal position, face up.

Marine chronometers are not adjusted to other positions, and if placed in any other than the horizontal will vary in rate.

The fuzee is always used to equalize the power. This facilitates their adjustment and enhances their accuracy.

They are frequently to be seen in jewelers' windows, as standards of time for the public. The mistaken idea prevails to some extent that a ship's chronometer is a more accurate timepiece than a fine clock. As a matter of fact, a well constructed and adjusted clock with a well compensated seconds, mercurial pendulum, located so as to be free from jar or vibration, is much more reliable.

Many of the chronometers used in show windows are inferior instruments and are often sadly neglected, the owner fondly supposing that cleaning once a year is all that is necessary. It is rarely, however, that more is not required. The main spring will have lost a portion of its energy, pivots may need polishing, a readjustment of the escapement may be called for and other things require attention.

When a chronometer receives its annual cleaning, the main spring should be tested with an adjusting rod. The adjusting rod is attached to the fuzee square and the chain is in place connecting the fuzee and barrel. The adjusting rod is provided with one or more slidable weights by means of which the rod may be balanced in a horizontal position by the force of the main spring. With the chain entirely on the barrel, the mainspring is wound to a certain extent by means of the ratchet on the barrel arbor, the amount of winding—setting up—being changed until an approximation to a uniformity of power is attained. When the mainspring becomes set to any extent it is impossible to secure accuracy of rate. This invariably takes place in the course of time, and if the old spring is not replaced by a new one the rate of the instrument is impaired. The same is true to a greater extent of the balance spring. In view of these facts, it will be readily understood that although a chronometer be cleaned at proper intervals, the pivots polished, etc., yet it may become inaccurate and unreliable as a timepiece.

The parts of the chronometer escapement are, referring to Fig. 95:

A, the escape wheel.

B, the locking detent.
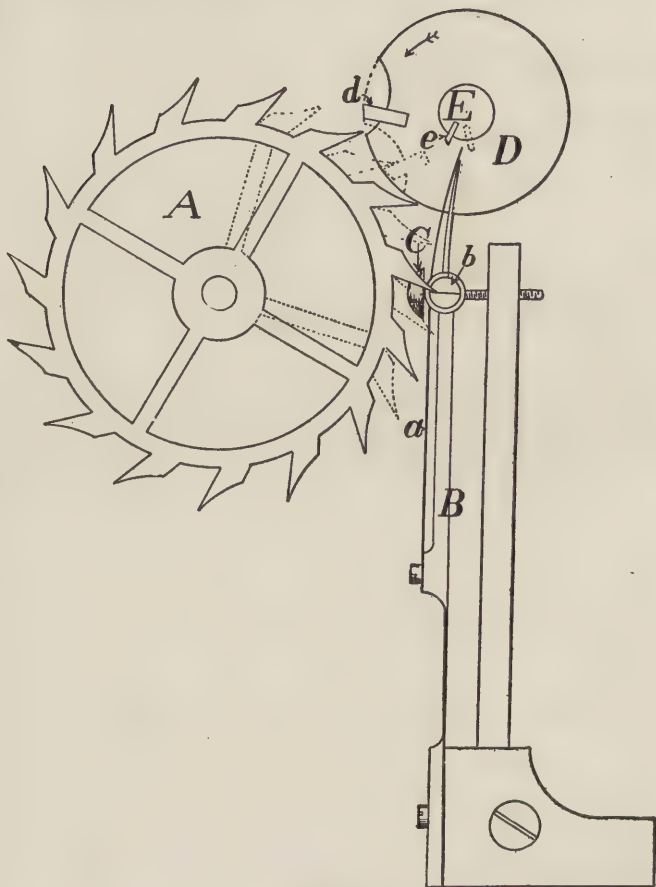
Fig. 95.

a, the unlocking spring, commonly called the gold spring, it being usually made of that metal.

b, the detent jewel.

C, the banking screw.

D, the impulse roller.

d, the impulse pallet.

E, the discharging or releasing roller.

e, the releasing pallet.

There are two principal forms of the chronometer escapement. That shown in Fig. 95 is called "the spring detent" and is generally used in marine instruments. The other, called "the bascule," meaning see-saw, is the form generally used in watches. In this form the detent is pivoted and a coiled spring, called the recovering spring, is colleted to the arbor carrying the detent, the outer end of the spring being secured in a stud attached to the watch plate. The office of the spring is to bring the detent against its banking, C, Fig. 96.

The chronometer escapement gives impulse to the roller only in one direction, usually when the balance vibrates to the left. Fig. 95 shows in broken lines the action when the balance, revolving to the left, as indicated by the arrow, receives its impulse. In this action the releasing pallet comes in contact with the extreme end of the gold spring and forces the detent aside, releasing an escape wheel tooth. While this is taking place, the impulse pallet has moved into the path of another escape wheel tooth, and when the wheel is released that tooth drops on the impulse jewel thus communicating an impulse to the balance. On the return excursion of the balance the releasing jewel lifts the gold spring from the detent and is allowed to pass on its excursion to the right. The outer end of the impulse jewel is flush with the periphery of the roller and passes between two teeth without contact.

Fig. 96 shows a plan view and an elevation of the bascule. It is shown in full lines with the balance revolving to the right as indicated by the arrow A. The releasing pallet is in contact with the gold spring, lifting it from the detent. The broken lines show the releasing pallet in contact with

the other side of the gold spring, forcing the detent from its banking and carrying the detent jewel to a point where it is about to release the escape wheel for the delivery of an impulse. The roller is rotating as indicated by the arrow B.
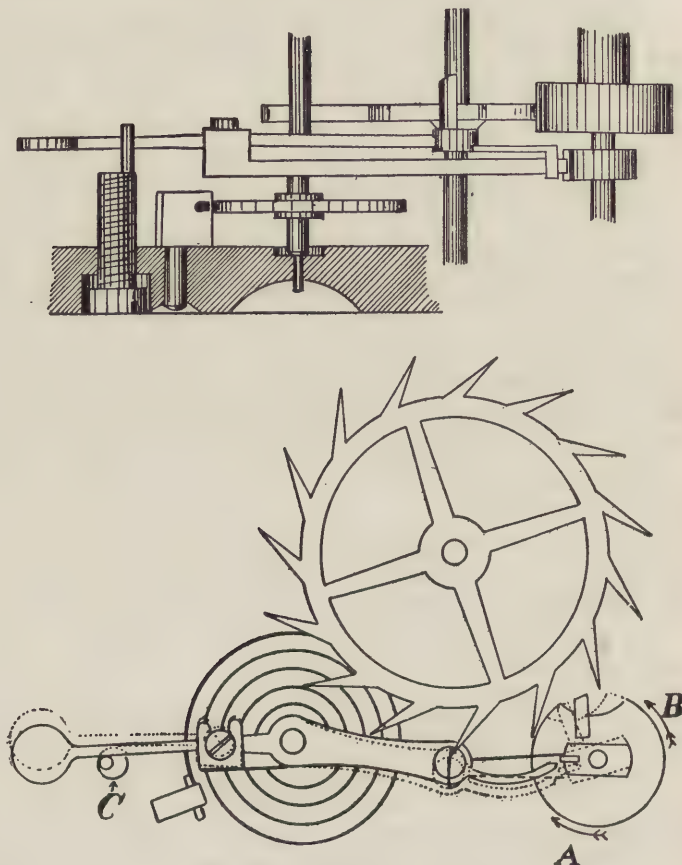
Fig. 96.

The elevation is for the purpose of showing the position of the parts as in the watch. It will be noticed that the extreme ends of the detent, gold spring, releasing roller and

releasing jewel, are all located beneath the impulse roller. The same condition prevails in the escapement depicted in Fig. 95.

A close scrutiny of the chronometer escapement will disclose the fact that fully four-tenths of the power is lost in the drop of the wheel tooth on the impulse pallet. There is also a loss of power in forcing the detent aside to release the escape wheel, and in raising the gold spring from the detent to allow the releasing jewel to pass. It has been shown that there is a loss of one-third in the lever escapement. The loss in the chronometer is still greater.

Many modifications of the chronometer escapement have, from time to time, been made, but the two forms shown are those found in general use.

No oil is used on the escape teeth or the impulse pallet, as a rule. In no case should the releasing pallet be oiled, for the reason that it would surely find its way between the detent and gold spring, with the result that an adhesive compound would be formed which would be very detrimental to the rate of the instrument.

CHAPTER VII.

THE BALANCE STAFF.—In replacing a broken balance staff in an American watch, it is seldom necessary to make one, it being only required to keep a moderate stock of staffs of the different watch factory makes to enable the repairer to find one to fit.

Here let me advise the watch maker to use genuine watch factory staffs. There are many imitation staffs on the market but the difference in the price is not enough to warrant the risk of getting one of inferior quality.

Care should be exercised in every particular in the operation of replacing of a balance staff.

Removing the old staff is a somewhat delicate operation, and if not performed intelligently and carefully is likely to produce a distortion of the balance which will entail much subsequent trouble. It is a practice, all too common, to drive out the old staff from the top without even removing the burr produced by staking on the balance. This invariably enlarges the hole in the balance, thus rendering it more difficult to stake the new staff and making it necessary to do a good deal of truing of the balance after the staff is staked to place. In addition to this it often enlarges the hole by stretching the metal more at one side than the other, increasing the difficulty of truing and often leaving the arms of unequal length, the only remedy for which is stretching the short arm, an operation which is not to be recommended and should only be used when absolutely necessary. Some workmen prepare a balance staff for driving out by turning off the burr produced in staking. It is difficult to perform this operation without cutting more or less into the balance arm. This lessens the amount of metal surrounding the

balance staff, allows the staking end of the balance seat to project more above the arm than is necessary and increases the difficulty of staking on the new staff.

A better way is to hold the collet shoulder in a split chuck and turn off a sufficient amount of the *hub* to enable the staff to be driven out from the *under side* of the balance. Indeed,
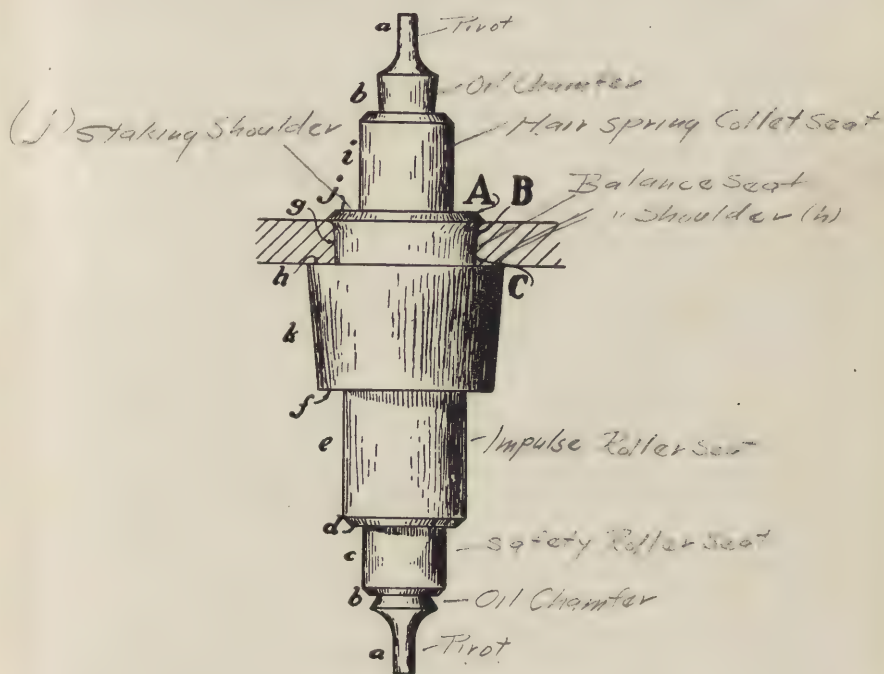
Fig. 97.

it can usually be pushed out without using a punch. This method has several advantages. The staking in of a staff, in addition to throwing a burr, stretches the upper part of the shoulder, making it larger at the upper than at the lower end, as illustrated, Fig. 97. It will be readily understood that even though the staking burr be removed driving out a balance staff thus stretched will slightly enlarge the hole **in**

the balance, while with the hub turned off and the staff driven out from the under side, no distortion takes place.

It is possible by following the instructions here given, to fit a new balance staff without having to re-true the balance. It should be understood, however, that in every case the balance should be tested for truth and poise. Before driving the new staff into the balance fit the pivots to the jewel holes and also the staking shoulder to the balance. The staff should go into the hole in the balance to the shoulder, or nearly so. It should fit perfectly without shake. It is permissible to open the hole in the balance slightly, but it is better to turn off the staking seat of the staff in case it is too large. Never use a staff with a staking seat so small that shake can be felt between it and the balance arm.

TREATMENT OF STEEL FOR BALANCE STAFFS.—Steel used for watch parts contains from 6/10 of one per cent to one and one-half per cent carbon. The larger amount is suitable for stem work, which usually is exposed to excessive strain, but for balance staffs a less amount is better. When a larger percentage is present there is a liability that in the hardening process a portion of the carbon may become crystallized. These infinitesimal crystals possess, to some extent, the abrasive properties of the diamond (diamond is crystallized carbon) and as a consequence the pivots sometimes pit the end-stones.

Extreme care should be exercised in hardening the steel from which a balance staff is to be made. If overheated the result is apt to be the same as described above, besides which, the pivots will be more fragile.

The repairer has no means of determining the exact percentage of carbon in steel, but the following method will enable him to determine to a close approximation, the proper amount.

Secure a piece of steel wire that by experiment has been

proved to be suitable for balance staffs. Keep this for comparison. Make a solution of one-fourth nitric acid and three-fourths water. Use this with a glass dropper as you would in testing gold. When it is desired to test a piece of steel, place it by the side of the sample piece and touch both with the solution. They will immediately turn a dark brown color. The intensity of the color will be proportional to the amount of carbon. If the piece being tested is darker than the sample the amount of carbon is greater and vice versa.

The hardening and tempering of a balance staff should be conducted with the utmost care. The proper heat to which the steel should be brought in hardening is about 1335° F. This is to say, it should be kept between 1320 and 1350. Watch factories are usually provided with pyrometers by which the exact degree of heat can be determined, but not so with the repairer; he must judge by the color. Steel heated till it shows cherry-red will be found to harden nicely. A little practice will enable the workman to detect by color, the required heat. If the steel is over-heated it will, on being broken, show a crystalline appearance at the fracture. When properly heated it will show a fine silk-like appearance under the double eye-glass. When it is too soft it will cut readily with a file. On attaining the proper heat it should be immediately plunged into some cold liquid. Cold cotton seed oil is excellent for this purpose. In its absence use lard oil, or water.

The steel after being hardened should be brought to the proper temper by heat. Brighten the steel wire its entire length with fine emery paper. Use a bluing pan which can be readily made from sheet copper. Place the steel in the pan and heat it over an alcohol lamp. The proper heat to bring it to is 540° F. This temper can be secured by noting the color. The change of color begins with a light straw, next a brown which gradually darkens into a purple, this changes to a dark blue, merging into a light blue. When the

latter change begins to take place remove the steel from the bluing pan.

Steel suitable for balance staffs may be procured of any material dealer. I would recommend using steel containing rather less carbon than Stubb's wire. Each rod should be sampled before using. To do this cut off a small piece, harden it and test it as described.

MAKING A BALANCE STAFF.—Sometimes it is necessary for the repairer to make a balance staff. This is generally the case when the watch is of foreign make, and is sometimes the case when of American manufacture. For instance: The workman may not happen to have one in stock for the particular make of watch he is to work on, and he may not have time to wait for one ordered from the factory or material dealer. In any case it will be a great saving of time to be provided with some quick means of getting the proper measurements accurately. It often happens that the old staff was not correct, which would of course preclude taking the measurements from this source.

In view of the above condition it is often a "cut and try" process to make a new staff. Indeed, I might say a rule of thumb method. Some workmen in making a staff will leave one or both of the pivots a little longer than necessary, securing the proper end shake by taking off from the ends of the pivots. This method is objectionable for the reason that when the endshake has been secured in the above manner the pivots may not be the proper length, a condition that is unworkmanlike and often the cause of trouble.

If the pivot is too short it increases the difficulty of fitting the jewel and is liable to be a means of drawing the oil away from the jewel hole. If the pivot is too long it increases the liability of injury by bending or breaking.

I shall now describe a simple device that can be quickly made, by the use of which all length measurements can be

readily taken from the watch and accurately transferred to the work while in the lathe; this with such unerring precision that when the staff is removed and the cement cleaned from it nothing remains but to stake it in the balance and drive the rollers to place. By following the directions given
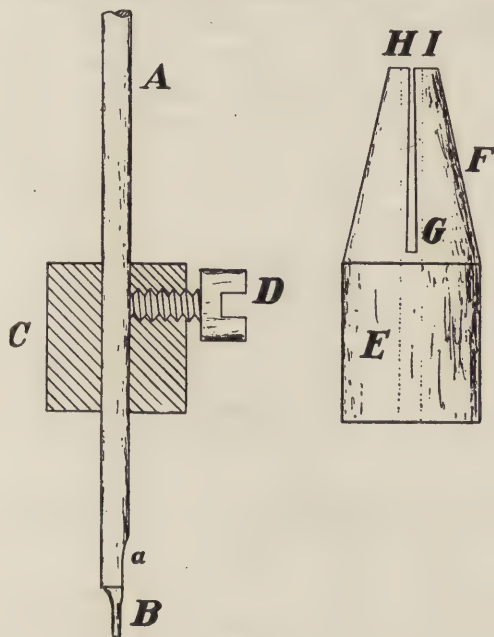
Fig. 98.

below the workman may feel absolutely assured that all measurements will be correct.

In order to avoid mistakes in specifying the different parts that will be referred to in the following description, the ordinary technical names used will be illustrated in Fig. 97.

Referring to Fig. 97, a, is a pivot; b, the oil chamfer; c, the safety roller seat; d, the safety roller shoulder; e, the impulse roller seat; f, the impulse roller shoulder; g, the bal-

ance seat; h, the balance shoulder; i, the hair spring collet seat; j, the staking shoulder.

Fig. 98 illustrates the device. A, is a piece of steel wire which may be about .6 mm. in diameter and any convenient length—say, an inch. B, is a cone pivot which should be small enough to enter the smallest balance jewel likely to be met with—say, .08 mm. The wire is cut away at a, for a purpose that will be apparent as we proceed. C, is a collar made to slip freely, but without shake, over the wire and is provided with a set screw, D, by which means it can be se-
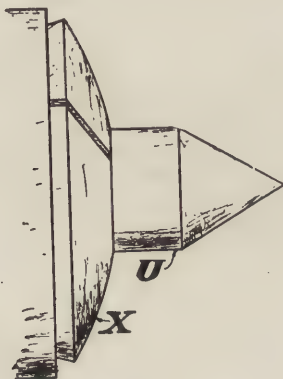
Fig. 99.

cured in any position on the wire. E, is another form of collar also made to slide over the wire but not requiring a set screw. The upper end, F, is made tapering and is slotted at G, which permits the closing together of the parts H and I, thus securing sufficient friction to retain it in any position on the wire. Three or four, each of these collars of different diameters suitable for various conditions that may arise, should be provided. This constitutes the entire equipment for measuring, and it will amply repay the workman to furnish himself with it, as it will enable him to execute the work more rapidly and more accurately.

THE MANNER OF PROCEDURE.—Let us assume that we have to make a balance staff for a full plate watch with double roller escapement.

Screw the potence in place with the balance jewel and endstone in position. Put the upper and lower plates to-
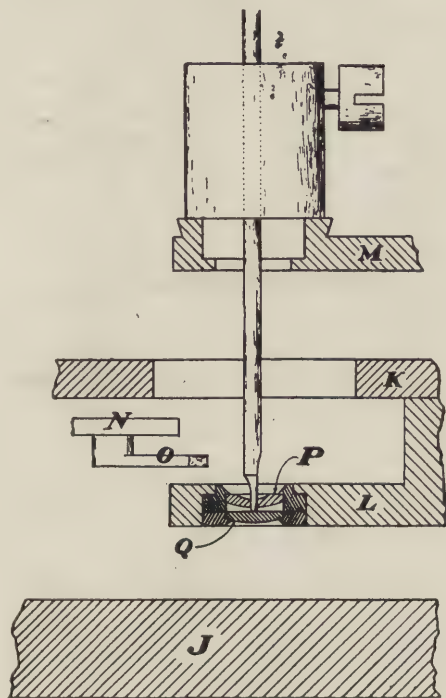
Fig. 100.

gether with the fork and pallets, and the scape wheel in place. Screw the balance cock to the upper plate without the upper jewel or endstone. The watch is now ready to take the required measurements.

Select a rod of steel wire of a little greater diameter than that of the hub of the staff to be made. Cut off a piece some-

what longer than required and harden and temper it. We shall call this piece, the blank. Holding the blank in a split chuck, turn a point on one end as shown in Fig. 99. In this figure, U is the blank and X the split chuck.

We are now ready to take the first measurement which
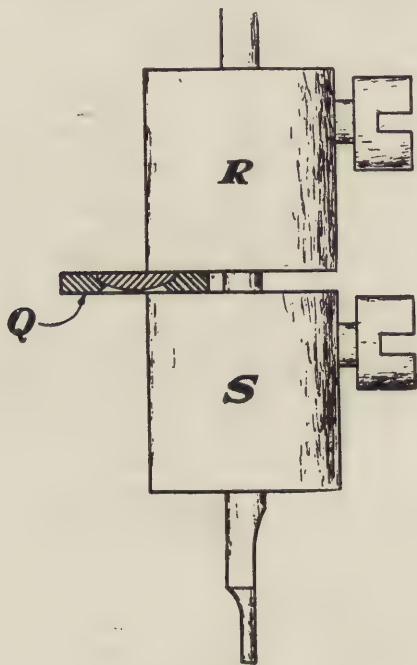
Fig. 101.

will be that of the entire length of the staff as illustrated by Fig. 100.

In this figure, J is the lower plate, K the top plate, L the potence, M the balance cock, N the fork horn, O the guard pin, P the balance jewel and Q the endstone. The gauge is shown in place to take the first measurements. Place a screw collar on the wire, and with the point of the latter in

the potence jewel, its extreme end against the endstone, bring the collar down to the top of the balance cock as shown, securing it in that position with the set-screw. Remove the gauge and place another screw collar below the
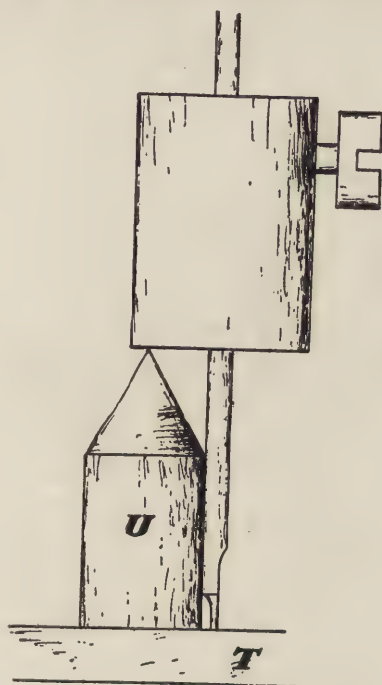
Fig. 102.

first, bringing it up to embrace the endstone between it and the upper collar as shown in Fig. 101.

In this figure, Q is the endstone, R the upper collar and S the lower collar. With the endstone held closely between the collars R and S, fasten the latter with the set-screw, then release R and bring it down in contact with S, securing it in that position. Now remove collar S. It will be seen that the distance between the face of collar R and the end of the

gauge pivot will now be the correct length for the new balance staff.

Now reverse the blank in the split chuck and turn the other end perfectly flat. Using the gauge as shown in Fig. 102 make the blank the exact length for the new staff.

In this figure T is a block upon which the flat end of the blank rests; U is the blank. With the end of the gauge pivot
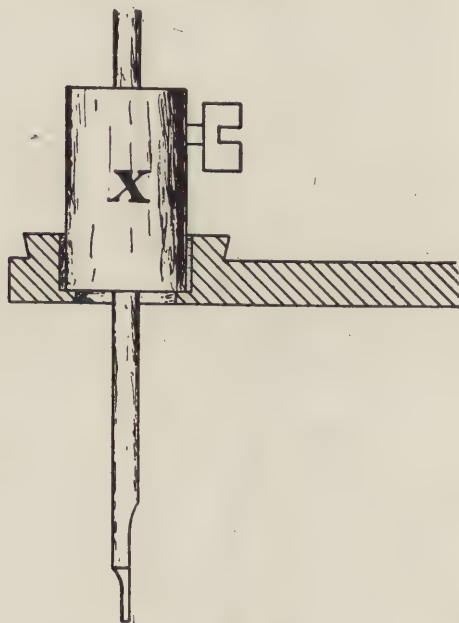
Fig. 103.

resting on the block and the lower face of the collar on the point of the blank, as shown in Fig. 102, the measurement can be accurately taken.

Another, and in some cases a more convenient method, is to take the measurements by bringing a collar against the jewel seat as shown in Fig. 103.

In this figure the balance cock and gauge only are shown,

X being the collar. It must be understood, however, that the gauge point should be in the potence jewel just as is shown in Fig. 100.

In measuring as is shown in Fig. 103, the face of the collar X rests on the balance jewel seat, and inasmuch as the
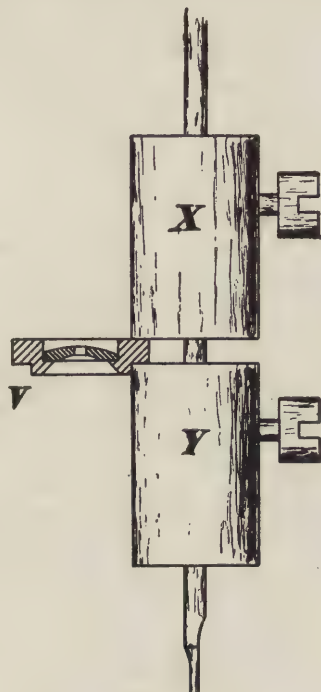
Fig. 104.

face of the endstone when in position is above this point to an amount equaling the thickness of the body of the jewel setting, that position is determined as follows: Using a second collar Y, Fig. 104, it is brought against collar X and secured there; then collar X is released and the balance jewel setting placed between the two collars as at V, Fig.

104. It will be seen that on removing collar Y that collar X occupies exactly the same position with relation to the gauge point as does collar R in Fig. 101.

MEASURING THE SHOULDER HEIGHTS.—The blank is now the proper length for the finished staff. Prepare a cement chuck as follows: Referring to Fig. 105 place a soft steel taper W in the lathe. Turn a V shape recess, b, in the end. In the bottom of this recess drill a small hole, c, a trifle
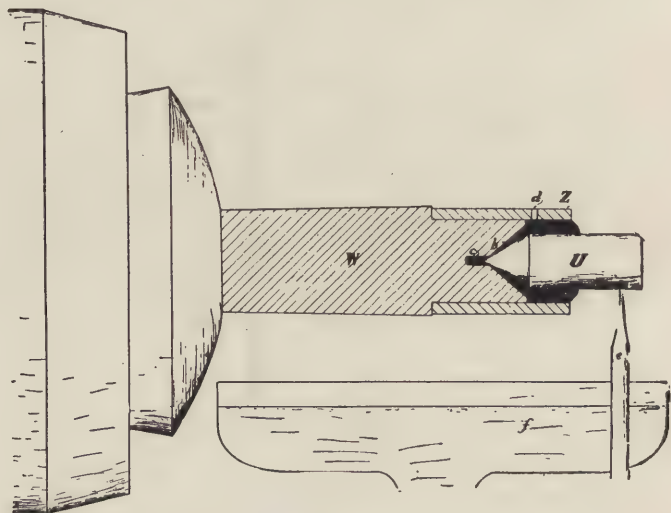
Fig. 105.

larger than the staff pivot is to be. Fit a shell, Z, on the upper end, allowing it to project beyond, as shown. It is well to provide this shell with a vent hole, d, to prevent the cement from being forced out at the front of the chuck by gas generated in heating. Heating the taper with the flame of a small alcohol lamp, fill the inside of the shell with cement. Bottom's lathe cement is excellent for the purpose. Insert the blank, U, into the shell pressing it in until it rests

firmly against the bottom of the recess, b, then, with the lathe running, hold a chisel-shaped peg, e, lightly on the T rest, f, and with the point against the blank, true it up while the cement cools. Care should be taken to insure that the pointed end of the blank is seated closely against the bottom of
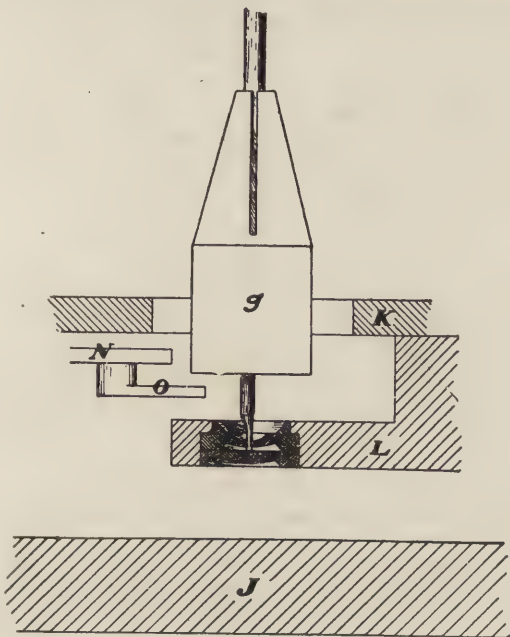
Fig. 106.

the recess in the chuck. The blank is now ready for forming the various shoulders that constitute one end of the staff.

It is the practice with some workmen to form the upper shoulders first, but the writer has always found it more convenient to form those on the lower end first. In accordance with this system, the first shoulder to be made is that which receives the safety roller (guard roller). To take the measurement, remove the balance cock.

Fig. 106 illustrates the method of taking the height. The drawing is similar to Fig. 100 except that the balance cock is removed. Sighting between the plates, bring the face of the collar g to a height above the guard pin that will bring the safety roller central with it.

Fig. 107 shows the method of using the measurement thus taken. In this figure the dotted lines show the end of the
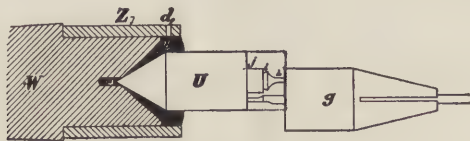
Fig. 107.

plank, U, before the pivot and safety roller are turned; the full lines show it after; h is the pivot, i the oil chamfer, and j the roller shoulder. These may be finished to the proper size before taking the next measurement. First turn and
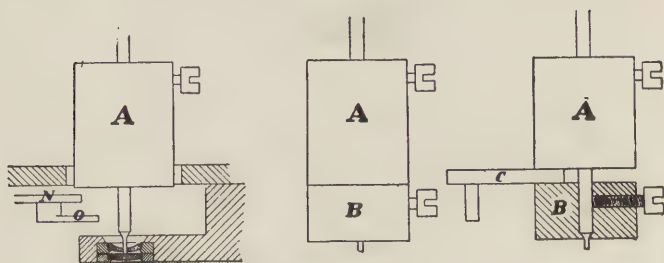
Fig. 108.

polish the pivot, fitting it to the lower jewel, which should be removed from the potence for that purpose. The oil chamfer may then be turned and the safety roller fitted, leaving a slight amount to drive after the staff is fitted to the balance.

Fig. 108 shows the method of taking the measurement for the height of the impulse roller. The view to the left in this

figure shows the gauge in position for taking the height of
the under-side of the impulse roller above the top of the
fork. It is evident that the collar A in this position will
not give the height for the shoulder that the roller is to be
driven to. In order to do this a collar must be raised to an
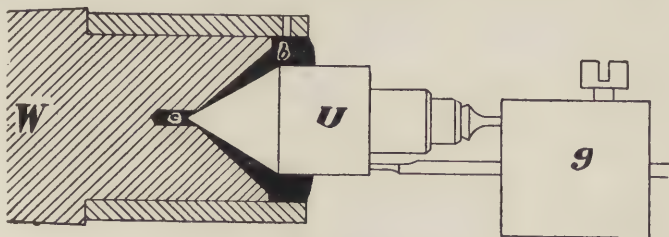
Fig. 109.

amount equaling the roller thickness. To do this accurately,
we bring a collar B up to A, securing B in place as shown
in the central view. We then release A and inserting the
edge of the roller C, secure A as shown in the view at the
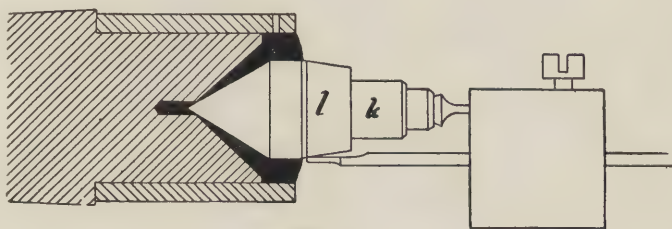
Fig. 110.

right. Upon removing collar B and the roller, collar A will
be at exactly the proper height. Using the gauge thus set,
as shown in Fig. 109, turn the impulse shoulder to the
proper height.

The bevel of the hub may now be finished as at l, Fig. 110.

It remains to determine the height at which to turn the
balance seat.

Fig. 111 shows how the measurement may be taken. It is assumed that the bevel of the balance staff hub has been finished to the full diameter of the wire as shown in Fig. 110. With the gauge point in the potence jewel, bring a collar D so that, sighting across the top plate, the face of the collar shall be the required distance above its upper surface. With the measurement thus taken, use the gauge as shown in
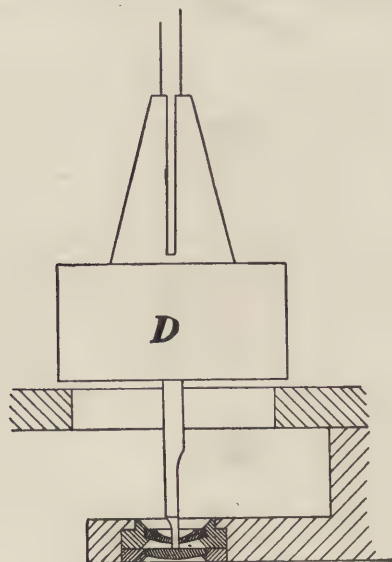
Fig. 111.

Fig. 110, and mark on the hub the point where the pivot touches it. Use a sharp pointed graver for this purpose. A mere scratch will suffice. The staff may now be reversed in the chuck, as shown in Fig. 112, and the balance shoulder, collet shoulder, upper pivot and oil chamfer finished. In these operations fit the balance to the staff so that there will be a little to drive, and fit the hair spring collet with the same condition prevailing. These various operations have been described in detail in order to make it clear to the

reader. As a matter of fact the operations may be performed in less time than it has taken to describe them.

There is one other form of this gauge which may be necessary in some cases. This we shall call a coupled gauge. Fig. 113 illustrates this without any detailed description. It consists of a friction coupler into which are inserted two wires each having a pivot turned at one end. These wires can be brought so that the pivots will just reach the end-stones as shown in Fig. 114.

In watches where the balance jewels are set directly into the plate and cock, without separate jewel settings, a gauge
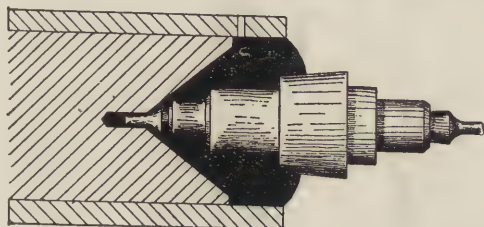
Fig. 112.

of this character may be used to get the entire length of the staff, after which the other form of gauge may be used for determining the heights. The coupler gauge will also be found very convenient for many other purposes.

TURNING AND POLISHING.—We shall now give a few brief instructions for turning and polishing the different parts of a balance staff. There are different methods used successfully in producing a polish. There are also different methods and forms of gravers. The workman must use his own judgment in these respects. There is, however, but one correct method for presenting the graver to the work. This we have attempted to show in Fig. 115.

In Fig. 115, W is the work, G a section of the graver. The work is assumed to be turning to the left—in the op-

posite direction from the hands of a watch or clock. The broken line extending radially from the work indicates where the cutting edge of the tool should be presented. The upper face of the tool forms an angle of ten degrees with this line, the clearance edge of the tool forming an angle of five degrees with a tangential line which is at right angles with the radial one. With a properly tempered and sharpened tool presented in the manner shown, high tempered steel may be readily cut. The difficulty experienced by un-

Fig. 113.

skilled or improperly taught workmen is that they are apt to present a tool for cutting in such a manner that it scrapes, rather than cuts, with a result that the work quickly glazes over, in which condition it is very difficult to get any tool to cut. Whenever this happens the glazed portion should be roughened with oil-stone powder, or emery, or else the cut should be started at some part of the work which is not glazed and worked along so as to remove the glazed portion.

Fig. 116 shows two gravers sharpened for the purpose of making balance staffs. At A the graver is shaped for the

purpose of turning the shoulders and such parts. The short straight portion at the right side represents the face of the graver where the clearance of 5 degrees is shown in Fig. 115. The graver shown at B has the point rounded for the purpose of turning the cone pivot.

The smoother the turning is made the quicker and better will be the polish. Attachments can be had for American
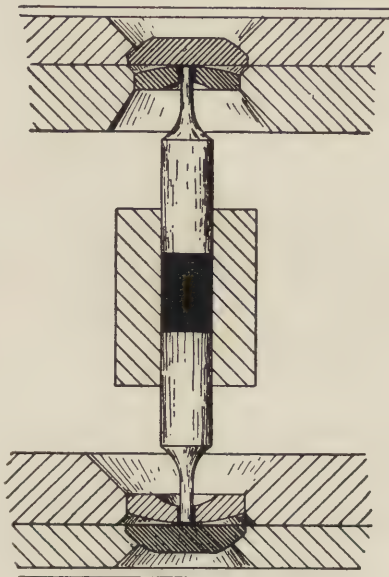
Fig. 114.

lathes, for carrying a small lap to be used in polishing. This lap can be adjusted to any desired angle, also to different heights. For grinding staffs and pivots, the lap may be of steel. For polishing, it may be of bell-metal, block tin, or well seasoned celluloid.

The work should be turned so that a little grinding, which is essential to prepare the surface, will bring it almost to the required size. If carefully done, the polishing will make

very little change. The oil-stone powder which is used for grinding should be put through an operation known as "settling." To settle oil-stone powder mix three or four tablespoonfuls of the powder in a quart bowl of water, stirring it up thoroughly. It should not be made to revolve, but simply be agitated by stirring it from side to side. Then allow it to stand for about thirty seconds; this will give time for the coarser particles to settle to the bottom. Then pour off the top liquid into another vessel and allow it to
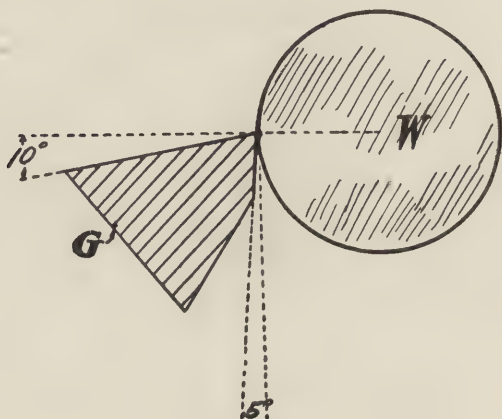
Fig. 115.

settle until clear. When settled, pour off the clear water and dry the powder which remains.

Various compounds are used for polishing, each having its advocates. Those generally in use are crocus, rouge, diamantine, and Vienna lime. These are sometimes used separately, sometimes combined. Oil is the best liquid to moisten the compound, which in every case should be crushed and blended thoroughly. Watch oil is excellent for this purpose, for the reason that the mixture may be kept for a longer time without danger of developing acid.

The device called a polishing block, found on the market, is a very neat device for keeping it. It is often made up in nests, one block above another, but when used in this form great precautions should be taken to avoid mixing the different grades of polishing or grinding compounds.

In mixing any preparation to be used for polishing steel, it is well to place the entire amount to be mixed at one time on the block upon which it is to be prepared. Do not add any of the compounds to that which may already have been placed to be mixed, during the process of mixing, but place the correct amount of oil and of polishing compound so that neither ingredient will have to be added to. In case
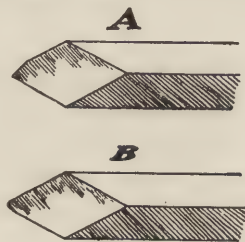
Fig. 116.

the first amounts put together should not produce a **mix**-ture of the proper consistency, throw it away and try again. The polishing compound should be quite thick and should be used on the polisher until it becomes almost dry.

Instead of using a lap, just as good results may be obtained with steel, or with bell-metal slips. The fine black, mirror-like polish seen on English watches is produced in this manner. Do not allow the work to become dry when polishing, but keep it moist by adding more polish as may be needed.

CHAPTER VIII.

Making The Balance.—The weight of metal contained in a watch balance is distributed over a considerable area. In an ordinary compensation balance the arms weigh about 15 per cent, the rim 55 per cent and the screws 30 per cent of the entire balance. These proportions are found suitable to give the arms just sufficient rigidity to sustain the rim and screws; to the rim, a sufficient amount of metal to reduce the dilation caused by centrifugal force to the minimum; and to the screws, enough weight to insure compensation.

The rim is composed of two metals, brass and steel, in the proportion of about three-fifths brass and two-fifths steel. The brass used is of a composition having about twice the co-efficient of expansion as the steel, the steel being low in carbon. These metals are smelted together thus forming a solid mass which must be free from blow holes, flaws and imperfections of every kind. The rim is cut apart in two places and the unequal expansion and contraction of the two metals is used to compensate for the errors produced by variations in temperature. How this is accomplished will be fully explained when the subject of temperature adjustment is taken up.

To comprehend the action of the balance in controlling and regulating the motion of the train and escapement it is well that the student should fully understand the meaning of the terms "radius of gyration" and "moment of inertia."

The radius of gyration is the distance from the center of the balance to a circular line where, if all the metal were concentrated, the effect would be the same as though distributed between the arm, rim and screws. In other words

the rate of the watch would be unchanged. This line is called the circumference of gyration and represents the mean distance of the effective weight.

The term inertia is applied to that property in all bodies which when at rest tend to keep them so and when in motion tend to maintain that motion. If we hitch a horse to a loaded wagon he strains to set it in motion. This is overcoming its inertia. If when in motion it is desirable to stop quickly he also strains and is pushed forward a certain amount before the motion ceases. This is also due to inertia. The moment of inertia is the effective value of the force necessary to overcome that inertia.
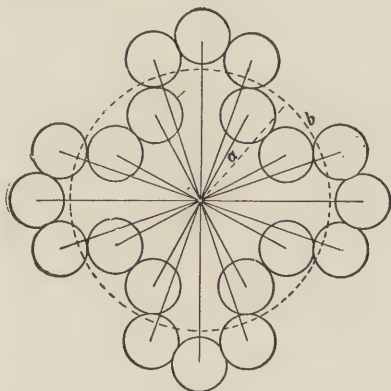
Fig. 117.

The exact location of the radius of gyration is very difficult to determine, but a comprehension of its distance may be obtained by reference to Fig. 117.

Fig. 117 represents 20 spheres connected together, but at varying distances from a common center. The radii are represented by lines from the center. If the lengths of all these lines were added together and the sum divided by the number of spheres, the mean, represented by line *a* would be the mean radius, and the line *b* the mean circumference. These lines in the figure do not exactly represent

the radius and circumference of gyration (which are obtained by a different process), but they will serve to illustrate the meaning of the terms. To ascertain the actual radius of gyration the balance should be divided into infinite atoms and the distance and weight of each atom from the center be ascertained. This process would also ascertain the effective force of the entire mass. This, of course, is impossible; but, briefly stated, the radius of gyration is the mean of the distance of the weight from the center and the moment of inertia is its effective value.

The inertia of the balance is primarily overcome by the
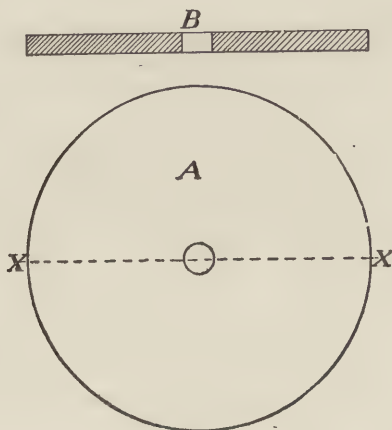
Fig. 118.

escapement, secondarily by the hairspring. From the instant that an impulse is given by the escapement the hairspring opposes its force to retard the motion until it finally overcomes that motion and the balance is brought to a state of rest. Then instantly the force of the hairspring is exercised to impart and accelerate motion in the opposite direction which continues until the escapement unlocks.

MAKING A COMPENSATION BALANCE.—Several methods have been pursued from time to time in making compensa-

tion balances. An interesting description of the method pursued at the time that Claudius Saunier wrote his excellent work, "A Treatise on Modern Horology," will be found in that work. In the early days of American watchmaking the factories used to solder the brass to the steel with silver solder. Another method was to immerse a bar of steel into molten brass until a coating on the outside adhered to it of sufficient thickness; then the bar was cut into sections from which balances were made.

It will be, without doubt, an advantage to the student to understand the modern method of balance making as pursued in American watch factories. Even though he never may have occasion to make a balance, a knowledge of how
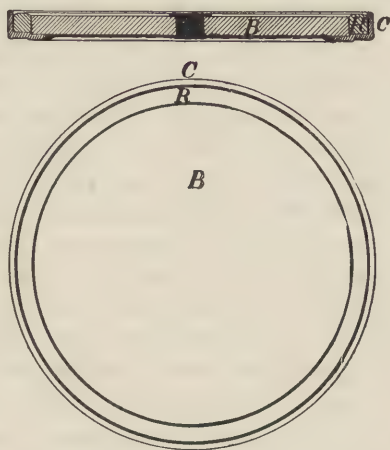
Fig. 119.

to do it properly will help him to distinguish between a perfect and an imperfect one.

The metals used should be free from flaws and of absolute uniformity of texture. Otherwise the expansion and contraction is likely to be unlike in both sections of the rim, thus interfering with adjustment. Discs are punched from strips of steel of the proper proportions. These discs are called "blanks."

A hole is drilled in the center of the blank, and carefully reamed to the exact size required for the finished balance. It is now mounted on an arbor and the outside and one face turned to size and absolutely true with the center hole. Fig. 118 shows the blank thus prepared. *A* is a plan view and *B* a section on line *x, x*. A capsule of an alloy having a large percentage of copper is provided as shown in Fig. 119.

Fig. 119 shows a plan view and section of the balance prepared for the muffle. *B* is the blank, *R* is the ring, and *C* the capsule. The blank, *B*, is driven into a recess in the capsule, *C*, as shown. It will be seen that a space is left between the outside edge of the blank and the wall of the capsule. In this space is placed a ring of brass, *R*. The ring having previously been covered with flux to secure a perfect joint between it and the blank, is now put in place between the blank and the capsule. The center hole is then filled with plumbago, made into a thick paste with some slightly glutinous liquid, beer being generally used. This prevents oxydation when heat is applied to fuse the brass ring. It is necessary that the center hole be preserved intact, as upon this depends the accuracy of the balance. The underside is also protected with the same substance at the joint between the capsule and the blank. The balance is next placed in a muffle and heated until the brass ring melts and becomes attached to both the blank and the capsule. The capsule, being of a more obstinate metal, does not melt. Fig. 120 is a plan view and two sections of the balance, *A* being a section before the balance is rolled and *B* a section after rolling.

After the firing operation all calcined matter is removed from the balance. The plumbago with which the center hole was filled is also carefully removed, leaving the hole exactly as when reamed. The balance is now faced off on both sides and a turning made on the outside edge which removes the capsule and a portion of the ring, bringing the

balance to a size that leaves just the right amount for roll-
ing. The balance is now ready for the compression of the
brass. This operation was formerly done by hammering.
The American method is by rolling. In rolling, a certain
amount of pressure (which begins gradually) is applied and
continued for a given time. This is the most critical opera-
tion in the manufacture of a balance, requiring skill and ex-
perience. If not rolled sufficiently the finished balance will
be soft; if rolled too much the steel as well as the ring will
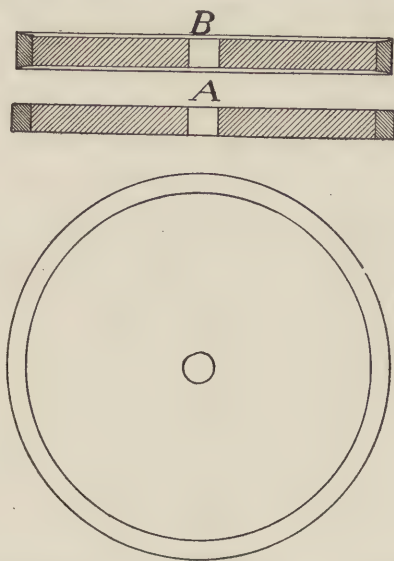
Fig. 120.

be compressed, with the result that there will be too little
steel and too much brass in the finished balance. The great
superiority of a rolled balance over a hammered one is that
in the former the brass becomes laminated by the rolling,
whereas in the latter the brass is driven down radially to-
ward the steel and often becomes disintegrated.

The balance is now "chambered" to nearly the finished
depth, after which it is "crossed." See Fig. 121. Crossing

is a technical term applied to removing that part of the steel intervening between the arms and rim. This operation, which used to be performed by sawing and drilling away the steel, is now done with a punch and die.

The balance is now drilled and tapped for the screws which usually number about 14. The balance, however, has several extra holes prepared, so that the screws may be moved during adjustment. The holes usually number from 22 to 26.

The balance is now ready for the final operations of
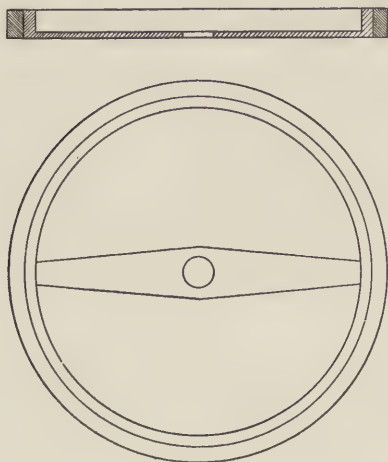
Fig. 121.

finishing, which are performed by turning, grinding, and polishing two sides.

MAKING THE HAIRSPRING.—So far as the writer is aware, a modern method of making hairsprings has never heretofore been published. Believing that the manufacture of a part upon which the accuracy of time so largely depends should be understood by every finished workman, to the extent of enabling him to produce a hairspring, we will give a detailed description of some modern methods.

Hairsprings for watches are usually of tempered steel. In some of the cheaper watches the wire is left soft. In non-magnetic watches the wire is of an alloy of palladium. Within the last few years experiments have been carried on in the use of a new alloy called nickel-steel. This alloy is composed mainly of steel and nickel.

The latest patents issued give the alloy for this purpose in the proportions by weight:

Nickel ....28.5 to 30.5 parts.
Iron ....61.6 to 66.2 parts.
Manganese .... 2 to 4 parts.
Chromium .... 1.5 to 1.8 parts.
Tungsten .... 1 part.
Vanadium .... 1 part.
Carbon .... 0.5 to 0.6 parts.
Silicon .... 0.3 to 0.5 parts.

The peculiarity of hairsprings of this and kindred alloys is that the elasticity—resistance to flexure—increases slightly with a rise in temperature. A steel spring decreases rapidly in elasticity under like conditions.

Steel wire from which hairsprings are made is usually low in carbon. It is first drawn round, to a diameter slightly less than the width of the finished flat wire. It is then rolled flat to the required thickness.

In drawing and rolling the wire great care must be exercised to avoid breakage and injury to the surface. Frequent annealing is necessary to prevent cracking. The reduction must be done, a very little at each drawing, and if the rolling is not always begun at the same end, the wire will break, so that in drawing and rolling it is passed from a spool or arbor through the plate or rolls and wound onto another arbor. It must then be unwound and wound on the original arbor before being again drawn or rolled.

When the hairspring made from this wire is to be left soft, a single piece of wire is wound on an arbor and is held in place by two plates, the whole being then heated.

The spring always opens more or less on being released after the heating process. The amount of heat applied determines the distance apart of the coils, consequently the strength of a spring of a given diameter. To produce a spring of a required strength by bringing the wire to the proper dimensions is a matter of extremely fine measure-
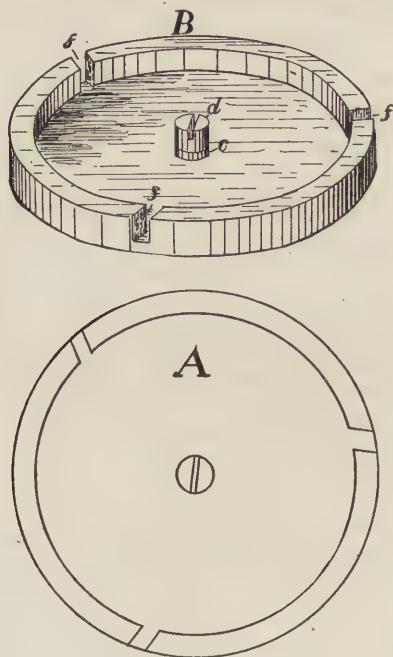
Fig. 122.

ment. In an 18-size hairspring, a difference of one ten thousandth part of an inch makes a difference in time of six minutes an hour.

When the hairsprings are to be hardened and tempered they are coiled up in a box, usually of copper, as shown in Fig. 122.

A, Fig. 122, is a plan and B a perspective view of a hairspring box. It is provided with a hole in the center through

which projects the end of an arbor C, which is provided with a screw D. . The arbor is slotted for the reception of the ends of the wires and the screw is to hold them in place. The box shown is for three springs and has three slots, each marked F, through which the wire enters. A cap is put down over the wire and the arbor turned until the box is wound full. The spaces between adjacent coils will then be twice the thickness of the wire. Wide coil springs are wound up four in a box; close coil springs, two in a box.

Fig. 123 gives an idea of how the springs look when wound in the box. The boxes must be examined after each time they are used and trued out if necessary. Every imperfection in the chamber will be reproduced in the hardened springs.

Fig. 123.

Various methods of hardening springs are in use. Some spring makers pack the boxes in charcoal. Others heat them in other substances. A preparation of chloride of sodium (common table salt) and a small percentage of cyanide of potassium is used by some makers. This is usually brought to a molten state in a crucible and the boxes immersed therein. Judgment and skill is required in the process of hardening. Too much heat will cause the

springs to adhere together; too little will not suffice to harden. On attaining the proper heat they are plunged into ice cold water. Sometimes a saline liquid is used, but if the boxes have been heated in melted salt this is not necessary. In all cases the liquid must be reduced to as low a temperature as possible so that the heating may be at the lowest degree necessary to harden.

The springs are now removed from the boxes and the temper drawn—generally in oil which is heated to 450 degrees Fahr., which is equivalent to drawing to a light straw color. The reason for this drawing is that when the springs are removed from the boxes they have a tendency to adhere together, and if separated before the temper is drawn are liable to be distorted. It is a curious fact that the strain put upon hard springs in separating them will put them out of shape, but will not do so if the temper has been started.

After separation, each three springs as coiled in the boxes are kept together, but separate from all the others until after the second drawing. After the first separation they are cleaned perfectly, then the groups of three are run together and drawn to a blue, after which they are finally separated and may be treated singly as necessary. In case the bluing is not perfect it may be removed by the following process:

Provide five suitable vessels which we shall call one, two, three, four and five. One, is to contain C. P. hydrochloric acid, unadulterated; No. 2 contains a saturated solution of C. P. cyanide of potassium; No. 3, a strong solution of the same; No. 4 is a vessel of cold water—if running water can be provided, so much the better; No. 5 is a vessel of sulphuric ether, which must be kept covered except when the dipping is being done, as it evaporates rapidly.

String the hairsprings to be treated on an iron wire; immerse for an instant into No. 1, then as rapidly as possible into No. 2, where they should remain about thirty seconds;

then into No. 3 for about the same time; then in No. 4, where they should be thoroughly rinsed for two or three minutes; then into No. 5, from which they may be dried in sawdust, or by shaking.

There are certain precautions to be carefully observed: Keep vessels No. 1 and No. 2 apart by a distance of at least two feet, otherwise the fumes are apt to mingle, rendering both unfit for use. When No. 2 assumes a bronze tinge replace it with fresh solution. Should the sulphuric ether show a tinge of yellow, replace that also.

The method described will produce good springs but will not insure the high finish so much desired.

Soft wire can not be brought to a high polish. It requires a certain amount of hardness to do this. To produce a highly polished spring the wire is drawn, while soft, to nearly the required thickness. It is then hardened and the temper drawn to 570 degrees Fahr. The wire is then drawn between diamonds, giving a polish that is still further heightened by some polishing compound. After polishing the wire is coiled up in boxes and treated as previously described. If care is taken to exclude the air in heating, the polish of the spring will not be marred.

A helical spring, such as is used on marine chronometers, is coiled up on a copper mandrel cut in grooves. These springs are hardened in form from the soft wire, and are polished after the springs are hardened.

For the benefit of those of my readers who wish to experiment on spring making I will say that hairspring wire, flattened ready to use, may be purchased in the market. It is generally of English make.

CHAPTER IX.

CLEANING A WATCH.—When a watchmaker takes in a watch to be cleaned he frequently finds, upon taking it apart, that other repairs are necessary. If the watch belongs to a regular customer and he has the entire care of it, it is fair to suppose that unless it has met with an accident, it is in good condition otherwise than the thickening of oil and accumulation of dirt; but if it belongs to a transient customer it is not safe to assume that such is its condition. It is, therefore, well to make a pretty thorough examination during the process of taking apart, finishing up with a final examination after the parts have been thoroughly cleaned.

EXAMINATION.—In describing the method of examination it is assumed that the watch is of American make. The same general directions will apply to any other kind.

Examine the case. See if it closes tightly, both front and back. See if it shows dents or other evidences of misuse. This will be an indication of the sort of treatment to which it has been subjected and is often a guide to the watchmaker in determining the cause of trouble. If it is a stem winder, try the winding and setting before removing from the case. It is frequently found that a watch winds or sets hard when in the case, due to a want of alignment of the case stem with the winding arbor in the movement. If a pendant set, see if pulling out the stem throws the setting properly into gear, so that the gearing works properly and with a correct depthing. See if the center arbor clears the crystal. This can readily be determined by putting a little watch oil mixed with rouge on the end of the arbor,

or top of the cannon pinion. On shutting the front bezel the result will be a visible mark on the glass if the center touches. Now open the case—both front and back—and see if the case screws hold the movement firmly in place. Remove the movement from its case and, if it has a dust band, see that it is freed from the barrel teeth. If it is not, the evidence will usually be found on the inside of the band. Examine the hands to see if they are properly fitted. The minute and hour hand should fit securely; the seconds hand just tight enough to be movable on the fourth pivot without endangering the train or escapement.

Remove the hands and dial and examine the dial wheels, including the cannon pinion, minute, and hour wheels. See that the hour wheel has just sufficient sideshake to be free on the cannon pinion without rocking, that the length of the pipe is just sufficient to be visible beneath the hand shoulder of the cannon pinion.

Examine the balance for truth. Stop it at the point of rest, then release it, allowing it to gradually come up to a motion. Defects in its truth in round or flat can be more readily detected while vibrating at not to exceed half a revolution. First, look directly down upon the balance to determine its truth in the round, then look at it from the side for truth in the flat. Examine the hairspring in the same manner to detect errors in the round, flat, circling and centering. Here let it be understood that when a spring is true in the round there will be no appearance of jumping; the coils will appear to uniformly dilate and contract. Centering is that condition which will produce an equal dilation and contraction, the coils being a uniform distance apart all around. There is another condition known as "training" a spring. This is the condition that exists when moving the regulator causes no distortion. That is, when the balance is at rest the spring will not touch either of the regulator pins when moved backward or forward. Nothing more need be said at this time about the condition of a hairspring

and balance. This will be taken up when the subject of "Springing" is reached.

A superficial examination of the escapement may be made at this point. Bring the roller pin in perfect line with the balance staff and pallet arbor. This is the point of rest. Try the shake of the fork slot on the roller pin. If a three-quarter plate watch, this can be done by grasping the fork with a fine, slim pointed tweezers; if a full plate, try it by grasping one end of the pallet steel while holding the balance as described, at the point of rest. Now slowly move the balance until a tooth of the escape wheel drops on one of the pallet stones; then move it back until it almost unlocks; while holding it there, try the shake of the fork slot again. If it is greater than when the parts were at the point of rest, it indicates a condition known as "fork short." Which is to say the jewel pin is too far back and should be brought forward. Move the balance about a quarter turn from the point of rest and holding it there press the fork against the roller edge. If the escape tooth unlocks it indicates a condition known as "roller depth shallow"; that is, the guard pin is too far back. Try this at different points at both sides.

Remove the balance. Examine the staff pivots to see if they are straight and not cut with grooves. A balance pivot is often injured by forcing the balance cock down when the pivot is not in the jewel hole. See if this condition exists. See if the roller pin is securely set, perfectly upright, face square to the front, and free from chips. If it is an oval pin the major axis should be at a right angle with a radial line from the roller center.

Let down the mainspring. If it is a three-quarter plate watch take out the pallets. Examine the stones for chips and other imperfections. See that the guard pin is perfectly upright, that the fork slot is smoothly finished and the sides parallel. Examine the pallet arbor pivots. If it is a full plate watch, of course this cannot be done until the

plates are taken apart. Now examine the entire train—all pivots, wheel teeth, pinion leaves, in fact all other parts of the watch except the jewels. These can best be inspected after the watch has been cleaned.

It is practically impossible to specify all of the difficulties that may be encountered in a watch. A few of the most common ones, only, have been cited. The locating of defects is necessarily largely a matter of judgment on the part of the workman.

CLEANING.—There are several methods pursued, good, bad, and indifferent, in cleaning watches. The writer, as a result of experience and observation, can confidently recommend the method here described. The equipment required is a gallon porcelain-lined kettle, two or three quart bowls, a wooden receptacle—drawer or box—of about a cubic foot space, for holding boxwood sawdust, a rather stiff brush to be used in washing the parts, two wires shaped as shown in Fig. 124. These wires should be about four one hundredths of an inch in diameter, bent as shown in Fig. 124. The triangle of any convenient dimensions. A is a hook formed on one end of the wire for the purpose of holding it to prevent the pieces strung thereon from coming off. A soft brush for removing any particles of sawdust that may remain on the parts should be also provided. If a vessel of sulphuric ether is provided and the parts immersed in it after removal from the alcohol, no sawdust will be necessary, as the ether will evaporate without leaving any residuum.

A strong solution of soap is made up in the porcelain kettle. One of the best kinds of soap to be used is crude whale oil soap. This solution is heated almost to the boiling point. One of the bowls should contain a solution of cyanide of potassium in the proportion of an ounce of cyanide to a pint of water. Another bowl should contain grain alcohol. Do not use denatured or wood alcohol. The

former contains certain chemicals injurious to some watch parts, the latter contains pyroligneous and formic acid. Benzine is not to be recommended. While it cuts grease rapidly, it does not act so well when the grease has solidified. A strong, hot solution of whale oil soap is more effective.

The work to be treated is strung upon the wires in such order as may be deemed best. Assuming that the watch is a South Bend, 16s, the following order may be observed: String upon one wire the train bridge, lower plate, barrel
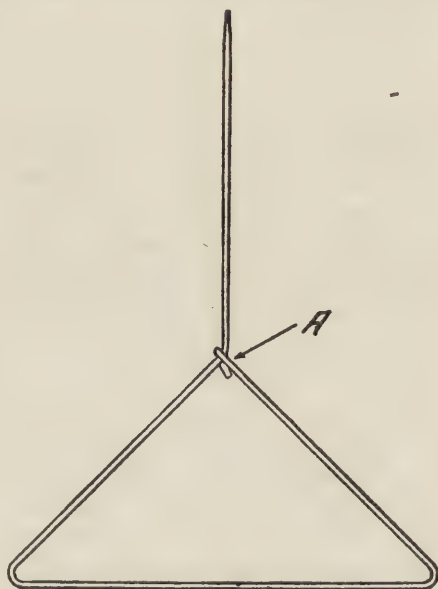
Fig. 124.

bridge, barrel, barrel head, balance cock, and pallet cock. Placing beads between the parts is an excellent way to prevent their scratching each other during washing, but is not necessary if the work is carefully handled. On the other wire, string the center wheel, third wheel, fourth wheel, escape wheel, hour wheel, ratchet, winding wheel, winding wheel cap, winding sleeve, sliding clutch, winding pinion,

clutch lever, setting lever, regulator and such other parts as
may be held on the wire. *But do not include the balance.*
The parts which have been strung should then be dipped
into the hot soap solution and brushed. Fig. 125 shows the
method of holding the parts while being brushed. The
hand forms a soft cushion that protects the wheels and more
delicate parts from injury. The other parts may be laid
upon a board while being brushed or they may be individ-
ually held in the fingers while strung on the wire. After
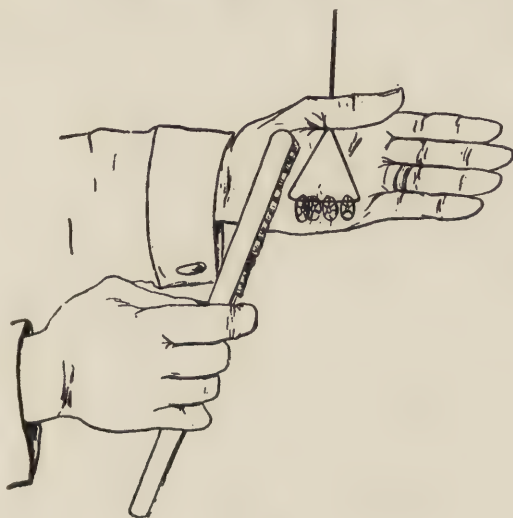
Fig. 125.

being washed they should be rinsed thoroughly, in running
water if available; if not, in a large vessel of clean water.
They are then immersed in the bowl of alcohol for not less
than thirty seconds, then dried in sawdust, or immersed in
ether. The pallets and balance should be treated separately.
The former should be washed quickly in alcohol and dried
in sawdust. It is permissible to wash the pallets in benzine
or gasoline, but in that case they should also be brushed or
rubbed with alder pith to remove the scum. The balance

may be washed carefully with a soft brush in alcohol with a patting rather than a rubbing motion, then dried in sawdust. It will not be necessary to remove the hairspring unless it should be desirable to true or poise the balance. If the balance is seriously corroded it may be advisable to clean it with the flat and the string buff suitable for the purpose; but if only tarnished it is better to simply wash it, particularly if the watch has been performing well.

In case any of the parts are found to be stained they may be dipped in the cyanide solution, but it is not desirable to do this unless absolutely necessary. Cyanide is a dangerous chemical to use on watch work. It has a strong affinity for metals, especially brass, nickel, and kindred alloys, and if not thoroughly removed is liable to corrode the piece. When it is necessary to use cyanide certain precautions should be carefully observed. If used on bridges or top plates having jewels of composition or low karat gold, the jewels should be removed before dipping the plates; otherwise a stain is likely to result which is very difficult to remove. Sometimes it may be necessary to treat the balance with a cyanide dip. In doing this extra precation is necessary for the reason that the least particle of cyanide remaining under the screw heads or in any aperture will surely result in corrosion; therefore, when a balance is treated it should be most thoroughly washed under running water, then immersed in alcohol or ether for an instant and dried. Do not allow a balance or a pair of pallets to remain longer than is absolutely necessary in alcohol or ether, remembering that the jewel pin and the pallet stones are fastened in with some preparation of shellac which is soluble in either of the liquids.

When jewel settings are found to be discolored they may generally be restored by buffing the top part with a fine buff and rouge and polishing the beveled part with a device shown in Fig. 126. This can be made from an old screwdriver. B is a sleeve placed on the lower end; A a piece

of felt inserted into the sleeve. Fine rouge is used as a polishing compound.

All jewels having endstones should be taken out and thoroughly cleaned.

Fig. 127 represents a form of tweezers that are very convenient to hold jewels while washing. They are provided with grooves at the points to receive the jewel setting. They are self locking, thus holding the jewel securely. A tooth brush is an efficient article to use for cleaning jewels. Wash them in soap and water, then releasing them from the tweezers rinse in cold water, immerse in alcohol and dry with a piece of chamois, being sure that every particle of scum is removed.

Fig. 126.

For removing and replacing the jewels use a jewel pusher as shown in Fig. 128. A is the pusher complete. It may be made of one piece or of a piece of wire set in a wooden or rubber handle. Brass is the best metal of which to make a pusher. The extreme end, a, should be flat and provided with a recess in the end as shown in the sectional view, B. The object of this recess is to prevent the possibility of touching the balance jewel, and thus injuring it, when pushing the jewel back to place. In pushing out the jewel the naked punch is used, but in pushing to place a polished jewel setting use two thicknesses of tissue paper between the end of the punch and the setting. The face of the pusher should be faced off occasionally. It is a very unworkmanlike thing to push out (or push in) a jewel setting with the tweezers.

Washing the barrel and barrel head has been referred to. There is a certain amount of hesitancy on the part of watchmakers to remove a mainspring for fear that the removal and replacement may cause it to break. There is practically no danger of breakage unless the mainspring has been distorted in removal. If taken out and replaced with a good mainspring winder there is nothing to be apprehended unless the mainspring has reached the limit of its life, in which case it is much better to have it break while in the watchmaker's hands than in the pocket of its owner.

Fig. 127.

Lifting out a barrel head with a screwdriver is very apt to raise a burr about the lifting notch.

Fig. 129 is a convenient little tool for lifting out the barrel head without marring it. A is a plan view, B is a side elevation. The extreme point is slightly curved as shown. The upper side, *b*, is flat; the under side, *a*, is rounded, to conform with the curve of the barrel. It should

Fig. 128.

be made of steel and tempered, the point being narrow enough to enter the lifting notch of the barrel head, and thin enough to go between the underside and the mainspring. The manner of using it is to insert it in the lifting notch with the rounded side resting on the barrel edge. In replacing a barrel head insert the head at one side and press the other side against the edge of your bench or other

flat surface. Care should be taken to avoid distorting the edge of the cover.

ASSEMBLING.—The parts being cleaned and the barrel put together, the watch is ready to be assembled. In assembling a three-quarter plate watch, the train is put in position on the lower plate with the pivots inserted in their respective jewels; but in assembling a full plate, it is much better and more convenient—when one becomes accustomed to the
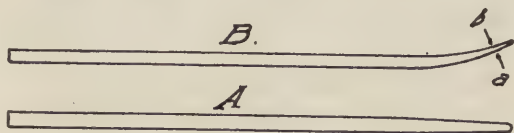
Fig. 129.

method—to assemble the train on the top plate. Hold the top plate in the left hand with the upper side down and put the train in position while thus held. The lower plate is now inverted. The first pivot to enter the lower plate is the center; the next, the fourth; and so on. Before putting the plates together such train jewels as are provided with

Fig. 130.

endstones should be oiled, but the balance jewels need not be oiled until after the rest of the watch is assembled.

It is a dangerous thing to use a glass or other tube oiler for the reason that fermentation is likely to occur from the oil being kept in the device. Once this has taken place it is almost impossible to get rid of it. The best way to keep oil is in a glass or agate oil-cup and the best form of oiler is shown in Fig. 130. It may be made of steel or gold. Do not use brass. The wire may be about 1/100 inch in diam-

eter and be set in a suitable handle. File it down to a long slim point, the extreme end about 5/1000 of an inch. Flatten this end as shown at A. By using an oiler of this char-
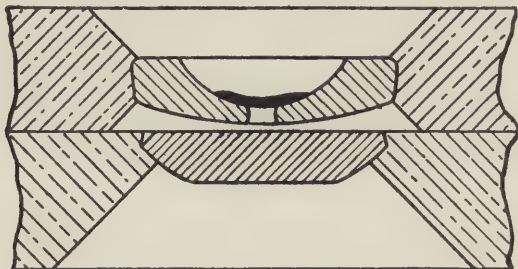
Fig. 131.

acter and size too much oil will not be delivered at one application, for the reason that if too much oil is taken out only a certain amount will remain at the point, the surplus running up on the taper of the oiler, as shown at *a*. Always
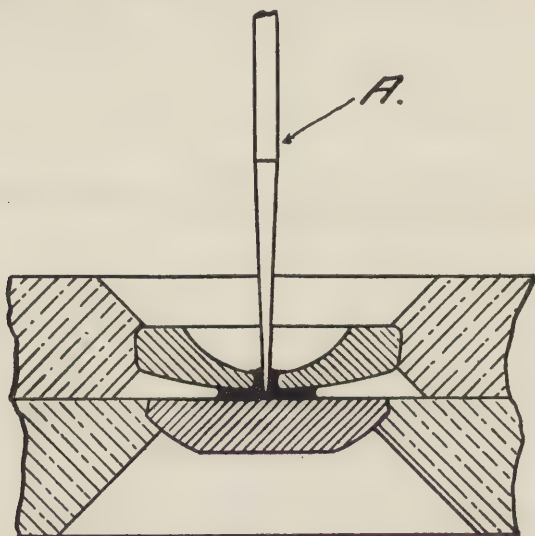
Fig. 132.

use an eyeglass when applying oil to the train or balance pivots. Oil the escape wheel teeth while the watch is running. A single dip of the oiler will suffice for all the teeth. Where too much oil is applied, it is liable to collect about the pallet steels, leaving the stones dry. Touch one tooth of the escape wheel; allow two to pass and touch another; allow two more to pass and touch a third. Putting the oil on the pallet stones is liable to cause it to collect about the steels as described.

Some workmen oil the jewels having endstones by putting a little oil on the endstone before driving it to place. This method requires such extreme care in order to avoid the oil spreading over the stone when driven home, that it is not advisable. It is better to do the oiling after the endstone is in place. The objection to this is that the oil does not always penetrate to the endstone, but this can be avoided by placing a drop of oil in the jewel cup and then inserting a fine pointed steel wire into the hole as illustrated in Figs. 131 and 132.

REPAIRING A WATCH.—The watch repairer, who is ambitious to be able to replace any injured or missing part of a watch, should possess a thorough equipment of modern tools, including a good lathe with attachments for wheel cutting, pivot polishing and the like. He should also acquire a knowledge of the theories, and mechanical principles involved in watch construction.

If he is not so equipped, he will occasionally find himself unable to repair a watch brought to him and be compelled to send it to some shop better provided. If the watch is of American make, it probably would not pay for him to actually make any part. Any part may be readily obtained from the factory where the watch is made; but if the watch is of foreign manufacture, the situation is often quite different. In this case the best that can be done is to ob-

tain the part in the rough.   Sometimes it cannot be obtained in any condition.

Our larger cities are well supplied with shops that make a business of doing such work for the trade.   The difficult jobs find their way to these places.

It is the object in this work to describe methods and rules applying to general repairs.   No make-shifts will be described.

The workman must necessarily depend on his own judgment in many cases.   Fixed rules cannot be prescribed to meet all conditions.   There are, however, certain mechanical laws which cannot be ignored without impairment of quality in workmanship.   It should be the aim of the workman to so familiarize himself with these, that he may be able to secure and maintain a high standard as a mechanic.

In our business, some of these laws have been and are being misconstrued; some are disregarded.   This is notably the case in a generally accepted rule for fitting mainsprings.

In Chapter I of this book, attention is called to certain laws governing the action of the main spring. The importance of a full understanding of these laws cannot be overestimated.

The main spring is the source of power.   If the main spring is defective or improperly fitted, accuracy of time is an impossibility.

One of the laws applying to main springs is: The main spring should occupy one-half the *space* between the periphery of the barrel arbor and the inside of the barrel wall.

This has been perverted into a rule which we have all heard and many of us have followed: "One-third arbor, one-third space, one-third spring."   This is taken to mean *radial* measurements for each one-third, and also that the space occupied by the spring when let down is one-third of the *radial* measurement.

The correct rule is: One-third barrel arbor, half of the remaining *area* to be covered by the main spring.

When half the *area* is covered by the main spring it will make no difference whether that spring is wound to the top, partially let down, or entirely let down. In all conditions
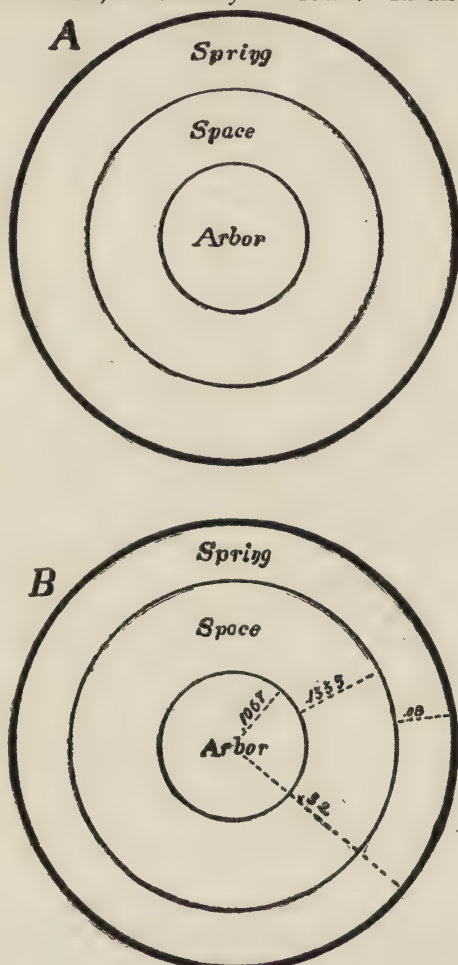
Fig. 133.

the space occupied will be one-half the space between the arbor and the inside of the chamber wall.

Fig. 133 illustrates the difference. In this figure A is the condition produced by the old rule; B is that produced by the new. It will be noticed that the circles dividing the spring and space occupy different positions in the two sketches. At A it divides that part of the chamber outside the arbor into two equal *radial divisions,* while at B, it divides it into two *equal areas.* At A the distance from the center of the barrel arbor to the dividing line is two-thirds the radius of the chamber. While at B the dividing line is three-fourths the radius.

SELECTING THE CORRECT DIMENSIONS FOR A MAIN SPRING.—This matter has been the subject of much experimentation by the author, the result of which is a simple formula for determining the correct dimensions. To do this,

First: Decide upon the number of hours that you wish the watch to run with one winding. This, in no case, should be less than thirty-four; thirty-six is much better.

Second: Ascertain the number of hours that one turn of the barrel will carry the watch. To do this, divide the number of teeth in the barrel by the number of leaves in the center pinion. The quotient will be the number of hours.

Third: Divide the number of hours the watch is required to run by the number of hours that one turn of the barrel will carry it. The quotient will be the number of turns required.

Fourth: Divide one-twelfth of the diameter of the barrel chamber by the number of turns of the barrel required. The quotient will be the thickness of the mainspring.

EXAMPLE.—Diameter of barrel chamber: .641″. Teeth in barrel: 84. Leaves in pinion: 14. Number of hours required: 36. Then 84÷14=6.

6 is the number of hours that one revolution of the barrel will carry the watch; then 36÷6=6 and 6 is the num-

ber of turns of the barrel required to carry the watch thirty-six hours.

Dividing the diameter of the barrel by 12:

$$12).6410(.0534$$
$$\underline{60}$$
$$41$$
$$\underline{36}$$
$$50$$
$$\underline{48}$$
$$2$$

Dividing one-twelfth of the diameter of the barrel by the number of turns required:

$$6).0534(.0089$$
$$\underline{48}$$
$$54$$
$$\underline{54}$$

This gives us .0089 for the thickness of the mainspring.

The proper length for the mainspring may be determined by the method described in Chapter I, and illustrated by Fig. 5.

Describe a circle inside of the barrel chamber, three-quarters of its diameter. Wind in an unbraced spring. If the coils lying against the wall of the chamber do not reach the circular line, the spring is too short. If they overlap the circular line, break down the spring until it exactly reaches it. It will then be the correct length.

In case it is desired to ascertain the correct length without trying the spring in the barrel, proceed as follows:

First: Divide one-eighth the diameter of the chamber by the thickness of the spring. The quotient will be the number of coils when the spring is down.

Second: Multiply seven-eighths of the diameter of the chamber by 3.1416, and multiply the quotient by the number of coils when the spring is down. The product will be the length of the spring.

EXAMPLE.—

$$8)\overline{.641}$$
$$\overline{.0801+}$$

$$.0089)\overline{.0801}(9$$
$$\underline{801}$$

9 is the number of coils when the spring is down.

$$.641$$
$$\underline{.0801}$$
$$\overline{.5609}$$

$$.5609$$
$$\underline{3.1416}$$
$$33654$$
$$5609$$
$$22436$$
$$5609$$
$$\underline{16827}$$
$$\overline{1.76212344}$$
$$\underline{9}$$
$$\overline{15.85911096}$$

About 16″ for length of spring.

Instead of using a spring in this watch .0089″ thick, if one .008″ thick is used, the watch would run more than forty hours.

It is recommended that the student test out the principles involved in these simple problems, which can be easily done, as will be described.

Mark a barrel as illustrated in Fig. 133 B. Wind in a mainspring that when down will extend beyond the three-quarter circle. Try the number of turns the barrel will give in winding up the spring. Now break the spring down until the inside coil just reaches the dividing circle. It will be found that the number of turns of the barrel in winding has been increased. It will also be found that when the spring is down with the inside coil corresponding with the dividing circle, that when wound up, the outside coil will also correspond with it. Finally, break the spring down until the inside coil falls short of the dividing circle. It will now be found that the number of turns in winding the spring has been lessened, thus proving the correctness of the law involved.

REPLACING A MISSING MEMBER OF A TRAIN.—Heretofore, one of the most difficult problems in connection with replacing a missing member, has been that of determining the proper number of teeth for a missing barrel. So far as the writer is aware no good method has been published or used for this purpose. To a considerable extent it has been a matter of "cut and try."
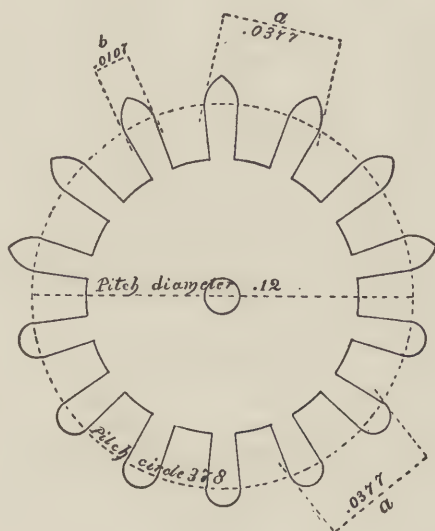
Fig. 134.

In case of a missing barrel we have for the calculation involved: the center distance from barrel to center; the number of leaves of the center pinion; and its diameter over the points of the leaves. But two of these elements are of any use in determining the number of teeth and the diameter of the main wheel. These two are the center distance and the number of leaves. The diameter over points of the pinion depends upon the shape of the leaves beyond the pitch circle.

The method we shall give has no element of uncertainty, but will give the correct number of teeth within a fraction.

Take the measurement across two adjacent leaves as shown at a, Fig. 134. Take the thickness of one leaf as at b. Subtract the latter from the former. The remainder will be the chordal pitch to a close approximation. Whatever error is introduced by measurement will have a tendency to make the distance a minute amount greater. But this will be no disadvantage, inasmuch as the circular pitch will be slightly greater than the chordal pitch.

Multiply the pitch thus obtained by the number of leaves in the pinion. Divide the product by 3.1416. This will be the pitch diameter. Divide the quotient by the number of teeth. This will be the diametric pitch of the pinion.

Now multiply the center distance between the barrel and center holes in the watch by 2 and subtract from the product the pitch diameter of the pinion. The remainder will be the pitch diameter of the barrel.

Divide the pitch diameter of the barrel by the diametric pitch of the center pinion. The quotient will be the number of teeth for the barrel. In case the result contains a fractional part, take for the teeth the nearest whole number. The fraction will be the result of some slight error, either in the pinion itself or in the manner of gauging.

Fig. 134 shows a center pinion with leaves having two different shaped points. The purpose of this is to demonstrate that the shape of the ends, so far as the measurement given is concerned, quite immaterial.

Should it be desired to determine the circular pitch after having secured the chordal pitch the following tables may be used:

Constants by which to multiply the chordal, to determine the circular pitch.

Leaves	Constants
8	1.026
9	1.021
10	1.017
11	1.013
12	1.009
13	1.005
14	1.001

For more than 14 leaves the amount is so trifling that it may be neglected.

Example: Center distance; barrel to center .42.

Measurement across adjacent leaves of pinion .0377.

Measurement of one leaf .0107.

First operation: Subtract the measurement of leaf from measurement across 2 adjacent leaves.

$$\begin{array}{r} .0377 \\ .0107 \\ \hline .0270 \end{array}$$

This gives us .027 as the approximate circular pitch.

Second operation: Multiply the pitch by the number of leaves:

$$\begin{array}{r} .027 \\ 14 \\ \hline 108 \\ 27 \\ \hline .378 \end{array}$$

This gives us .378 for the pitch circle.

Third operation: Divide the pitch circle by 3.1416:

$$\begin{array}{r} 3.1416).378000(.12 \\ \underline{31416} \\ 63840 \\ \underline{62832} \\ 1008 \end{array}$$

This gives us approximately .12 for the pitch diameter

Fourth operation: Divide the pitch diameter by the number of leaves:

$$14).12000(.00857$$

$$\begin{array}{r} 112 \\ \hline 80 \\ 70 \\ \hline 100 \\ 98 \\ \hline 2 \end{array}$$

This gives us approximately .00857 for the diametric pitch.

Fifth operation: Multiply the center distance by 2 and subtract the pitch diameter of the pinion therefrom.

$$\begin{array}{r} .42 \\ 2 \\ \hline .84 \\ .12 \\ \hline .72 \end{array}$$

This leaves .72 for the pitch diameter of the barrel.

Sixth Operation: Divide the pitch diameter of the barrel thus obtained by the diametric pitch of the center pinion

$$.00857).72000(84$$

$$\begin{array}{r} 6856 \\ \hline 3440 \\ 3428 \\ \hline 12 \end{array}$$

This gives us a quotient of 84 and a small fraction. The number of teeth will therefore be 84.

Fig. 134 shows graphically how the gaugings are taken on the pinion.

To replace a center pinion proceed in the same way except that the barrel is taken first, from the first to the third operations inclusive; then for the fifth to the seventh inclusive. The same rule applies to winding and setting work.

To determine the proper numbers for teeth and leaves for other members of a train is comparatively simple.

In all modern watch trains carrying seconds hands, the sixty revolutions of the fourth wheel to one of the center wheel is produced by multiplying by 7½ and 8; 7½ times 8 being 60. If one revolution of the center carries the third wheel eight times, then one revolution of the third will carry the fourth seven and a half times, and "vice versa."

To Find the Number of Teeth for a Center Wheel. —If the number of leaves in the fourth pinion goes into the number of teeth in the third wheel eight times without a remainder, the leaves of the third pinion multiplied by seven and a half will give the teeth for the center wheel.

If the leaves of the fourth pinion go into the third wheel seven and a half times without a remainder, the leaves of the third pinion multiplied by eight will give the center wheel teeth.

To Replace a Missing Third Wheel and Pinion.— When the center wheel divides by eight without a remainder the quotient will be the number of teeth for the third pinion, and fourth pinion multiplied by seven and a half will be the number of teeth for the third wheel.

When the center wheel divides by seven and a half without a remainder, the quotient will be the leaves for the third pinion, and eight times the leaves of the fourth pinion will be the number of teeth for the third wheel.

To Replace the Missing Fourth Wheel and Pinion. —When the leaves of the third pinion go into the center wheel eight times without a remainder, dividing the third wheel by seven and a half will give the number of leaves for the fourth pinion. When the leaves of the third pinion go into the center wheel seven and a half times without remainder, dividing the third wheel by eight, will give the number of leaves for the fourth pinion.

To Find the Number of Teeth for the Fourth Wheel.—First determine whether the watch is an 18,000 or a 16,000 train. This may be done by comparing the motion of the balance with that of another known train, or its vibrations may be counted for half a minute or more.

An 18,000 train balance gives 300 vibrations a minute, if alternate vibrations are counted (which is more convenient) they will be 75 in half a minute.

A 16,000 train—which is actually 16,200—gives 270 a minute, or 67½ alternates in half a minute.

When the watch is found to be an 18,000 train, multiplying the escape pinion by 10 gives the teeth for the fourth wheel.

When the watch is a 16,000 train, multiplying the escape pinion by 9 gives the teeth for the fourth wheel.

To Replace a Missing Escape Pinion.—The teeth of the fourth wheel will always be divisible by either 8 or 9 without a remainder and the quotient will be the number of leaves for the escape pinion.

The escape wheel teeth will of course be fifteen in all cases.

It is seen that the calculations for the teeth and pinions in a modern watch train is a simple matter. For other trains that do not carry seconds hands, the manner of procedure is somewhat different.

Rule for Calculating any Train of Wheels.—Trains are divided into two classes, simple and compound. Simple gearing consists of two or more wheels meshing directly into each other, each on its own journals or bearings. Compound gearing consists of a series of wheels and pinions, two or more mounted on the same staff.

In simple gearing, the difference between the number of teeth in the first and last members of the train determines their respective revolutions, irrespective of the number of

members or the number of teeth in the other wheels; the intermediate wheels simply transmit the motion from one to the other.

In compound gearing every member of the train enters into the calculations. To make these calculations three things are predetermined: The number of revolutions the last wheel in the train gives for one of the first; the number of members that constitute the train; the number of leaves to be given to each pinion.

RULE.—The prime factors of the product of each pinion and the number of revolutions of the last wheel, multiplied together and arranged in the number of groups corresponding with the number of wheels required, gives the numbers of teeth for those wheels.

For an example we will calculate the train, from the center wheel on, for an 18,000 train watch.

First operation: The number of teeth in the escape wheel is fixed at 15. Inasmuch as each tooth delivers two impulses to the balance, we will divide 18,000 by twice the number of escape teeth—30.

$$30)\,18000\,(600$$
$$\underline{180}$$

The number of revolutions required of the escape pinion is therefore, 600 per hour.

Second Operation: We will select for the number of leaves in the pinions; 9 for the third; 8 for the fourth; 7 for the escape. The number 9 selected for the third is unusual. It is done for the purpose of demonstrating the adaptability of the rule to all cases.

Multiply the pinions and revolutions together:

$$
\begin{array}{r}
9 \\
8 \\
\hline
72 \\
7 \\
\hline
504 \\
600 \\
\hline
302400
\end{array}
$$

Ascertain the prime factors of this number:

```
2) 302400
2) 151200
  2) 75600
  2) 37800
  2) 18900
   2) 9450
   3) 4725
   3) 1575
    3) 525
    5) 175
     5) 35
        7
```

This gives us as prime factors six 2s, three 3s, two 5s and one 7.

We will take for our first group two 3s and three 2s.

```
  3
  3
  9
  2
 18
  2
 36
  2
 72
```

This gives us 72 teeth for the center wheel.

We will take for the next group one 5, one 3 and two 2s, which multiplied together will give us 60 teeth for the fourth wheel.

We now have left one 7, one 5, and one 2, which multiplied together gives 70 teeth for the fourth wheel.

This completes the train, which it will be seen is correct for the purpose required. The center wheel has 72 teeth and as the third pinion has 9 leaves the center will give it 8 revolutions. The fourth pinion has 8 leaves and as the

third wheel has 60 teeth, it will give to the fourth 7½ revolutions. Seven and a half times 8 being 60, the center wheel will give the fourth pinion sixty revolutions, which is correct for carrying a second hand. The escape pinion having 7 leaves and the fourth wheel 70 teeth, the fourth will cause the escape to revolve ten times. The number of revolutions will therefore be 10 times 60, or 600.
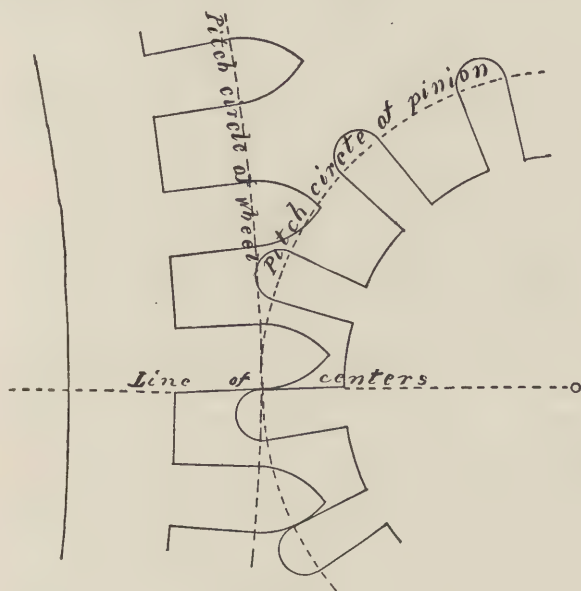
Fig. 135.

DEFECTIVE DEPTHING.—In the second chapter of this treatise the principles involved in watch gearing are fully and already explained. The watchmaker should study this portion carefully in order to be able to detect any defect arising from improper depthing. Perfectly designed and executed trains of wheels and pinions are capable of transmitting power uniformly and with slight loss. Neglect of the laws governing gearing—called depthings—entails un-

even action and loss of power in proportion to the magnitude of the neglect.

In a watch train, from the barrel to the escape, the wheel is always the driver. Where this is the case and the depthing is correct, the points of the wheel teeth and the flanks of the pinion leaves come into contact—and those portions only. By the point is meant that portion of a wheel tooth or pinion leaf that extends beyond the primitive
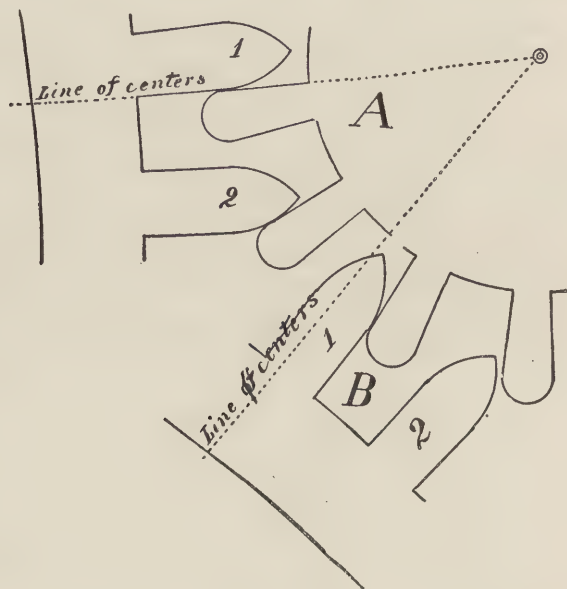
Fig. 136.

diameter—pitch circle. This is illustrated in Fig. 11, but as that figure is on a small scale, it is deemed well to explain it here in connection with a figure of more ample dimensions.

In Fig 135 the center of the pinion is shown, but the scale on which the drawing is made is too great to show the center of the wheel. The line of centers is a straight

line connecting the centers of wheel and pinion. The primitive diameter is the diameter to the pitch circle, and does not include the points of the teeth or leaves. It will be observed that the pitch circles touch each other only at the line of centers.

Those portions of the wheel teeth and the pinion leaves which project beyond their pitch lines are called the faces:
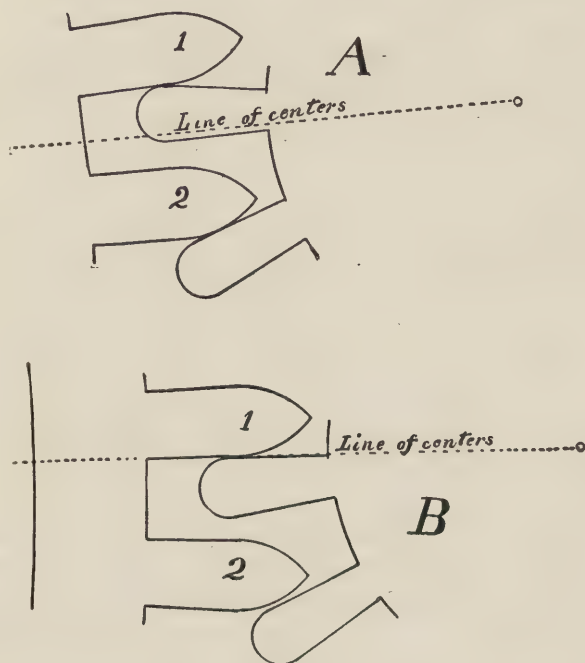
Fig. 137.

the portions that extend from the pitch circle toward the center are called the flanks. The circular pitch is the distance measured along the pitch circle from the center of a tooth to the center of the next adjacent one. The circular pitch of a wheel and that of the pinion into which it gears should be exactly alike. As has been explained, when the

wheel is the driver, the faces of its teeth contact with the flanks of the pinion leaves. The flanks of the wheel teeth and the faces of the pinion leaves should not touch each other. When this condition exists power is transmitted uniformly and with the minimum of loss. It is commonly called "a smooth depthing."

Fig 136 shows the action of a correct depthing. At A the tooth 1 has just begun its action as it should on the line of centers. The tooth 2 has delivered its full impulse. At B the tooth 1 has passed beyond the line of centers and the tooth 2 is now some distance from the pinion leaf to which it has delivered an impulse. The tooth 1 will continue
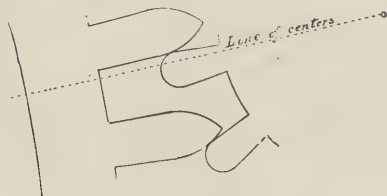
Fig. 138.

its contact until it has reached the point shown by tooth 2, in A. Then the succeeding impulse will be delivered by the next approaching tooth, and so on.

Fig. 137 shows the action when the pinion is too large. A, tooth 1, is where the impulse begins, which it will be observed is before the line of centers is reached. At B, tooth 1 has reached the line of centers and tooth 2 has left the pinion leaf. In this case the leverage is greater at the beginning than at the end of the engagement.

Fig. 138 shows the action when the pinion is too small. Here also the action begins before the line of centers and is more unfavorable to the transmission of power than the depthing shown in Fig. 137, for the reason that in no part of its action does the wheel tooth deliver its force on the flank of the pinion leaf. Throughout its entire action the faces of the teeth and leaves are in contact and exercise

what is called an engaging action which is attended by an excess of friction. It also increases the pressure of the pivots against their bearings, all of which interferes with the transmission of power.

By far the most serious error is an improperly sized wheel. Fig. 139 shows the effects of both large and small wheels. A is the large wheel, which begins its action beyond the line of centers. It will be noticed that at the beginning of the action tooth 1 contacts with the flank of the leaf at a considerable distance from the pitch circle of the pinion and ceases its action much nearer to it; also that the angles of contact are such that there is a constant increase of power as the tooth passes from the position shown by tooth 1 to that shown by tooth 2. A watch with a depthing in this condition will evidence a marked picking up and falling off in the motion of the balance, corresponding with the intervals between the beginning and ending of each impulse of a wheel tooth on a pinion leaf. As each tooth begins its impulse, the motion of the balance will rapidly fall off, then gradually pick up till the next tooth begins its action. This is repeated at each impulse.

B shows a small wheel. This begins action before the line of centers under the same unfavorable conditions shown in Fig. 138, where the pinion is small.

When the motion of a balance varies at regular intervals the cause may often be traced to a bad depthing and the particular depthing may be found by observing the length of those intervals. If it is in the barrel and center depthing, divide one hour by the leaves of the center pinion. Thus: If the center has 14 leaves, 1/14 of an hour being 4 minutes, 17 seconds, the intervals between falling off of motion will be that amount. If the center pinion has twelve leaves the intervals will be 5 minutes. If the falling off is caused by the center and third depthing, divide an hour by the teeth in the center. If the center has 80 teeth, the intervals will

be 45 seconds. If the center has 75 teeth, the intervals will be 48 seconds. Beyond this the intervals will be so short that it would be difficult to detect them.

To determine the nature of the difficulty in a defective depthing, set a depthing tool to the center distance of the wheel and pinion and place them in the tool. It is well to prepare a depthing tool for this special purpose. The
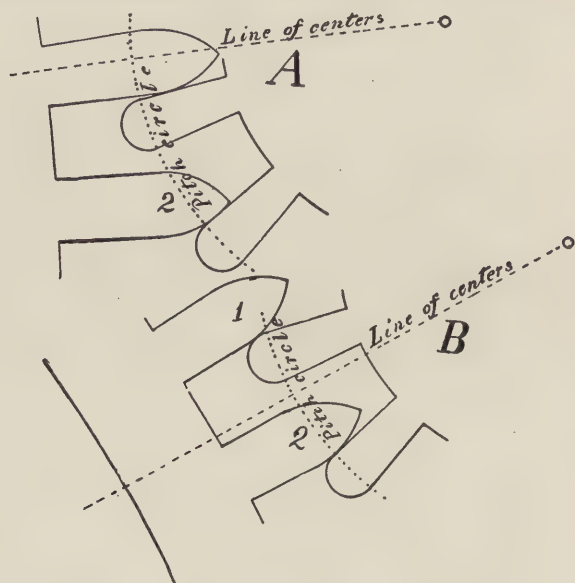
Fig. 139.

spindles of the ordinary depthing tools are too long to permit the use of a short focus eye-glass for examining the action. Shorten the spindles about one-half, using only the female end. The object thus obtained is that the examination can be made through a short focus glass, the sight being directed directly down on the depthing.

When the trouble is caused by a large wheel it may be remedied by topping.

In bridge watches of foreign make it sometimes is found that a pinion is out of upright and that correcting this fault will remedy a bad depthing. The steady-pins do not always fill the holes in the plate, thus allowing the bridge to move from side to side. This condition should be corrected and it can sometimes be accomplished by upsetting the pins on the ends. Where this cannot be done to advantage new steady-pins will be required and possibly rejeweling the bridge.
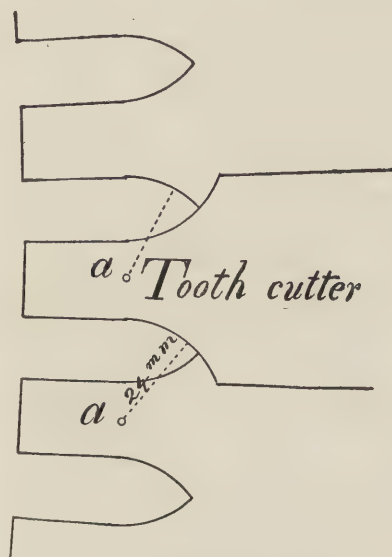
Fig. 140.

MAKING A WHEEL OR PINION CUTTER.—Wheels of various diameters and numbers of teeth can be found in the market, but it sometimes occurs that a particular number of teeth and dimension of wheel cannot be secured. In such case it is well that the workman should be able to make a cutter for the teeth or leaves. In American watch factories the forms of these cutters are produced on machines especially designed for that purpose. The following method will

enable any watchmaker possessing a good lathe and its attachments to make a cutter as good as the best.

Fig. 140 shows a cutter of proper form for cutting the teeth of the wheel represented. Such cutters are always made to cut away the spaces between the teeth, that portion of the cutter which forms the faces of the teeth extending considerably beyond their points. The curvature of the cutter forms the faces which in this case are arcs of a circle from the center a.
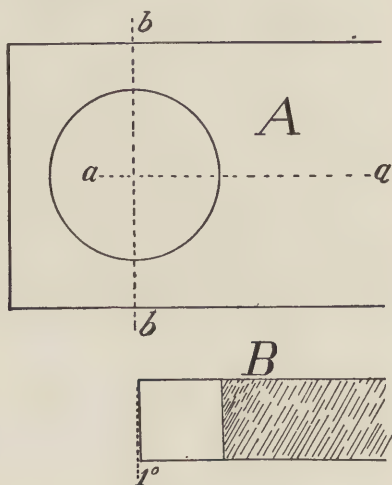
Fig. 141.

Procure a piece of square steel rod of the proper size to be held in the tool post of the lathe. Drill a hole near one end of the proper diameter to produce the desired curve of the teeth.

Assuming that the distance from the point a, Fig. 140, is .24 mm., this being the radius, drill the hole .48 mm. as shown in Fig. 141. In this figure A is a top view, B a section on line aa with the end cut off on line bb at the same angle at which the hole was drilled; shown at B as 1 degree. Drilling the hole at an angle with the face will of

course make the shape at the cutting edge slightly eliptical. Increasing this angle will make it still more eliptical; that is, the difference between the major and minor axis will be increased. In this way a close approximation to an epicy-cloidal tooth may be secured. After properly forming as described the cutter may be hardened, when it can be used to form a lap as shown in Fig. 142.

Rough out a circular lap or blank and mount it on an arbor in the lathe. With the cutter mounted in the tool post, bring it against the edge of the roughed blank as shown. After forming the edge with this cutter trim off
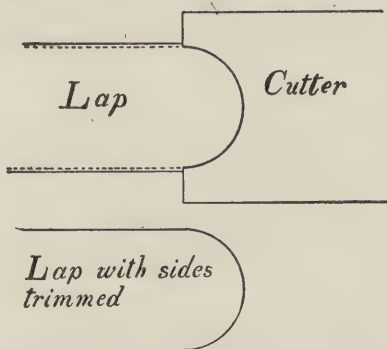
Fig. 142.

the sides until they match up with the curved ends, as shown. This can be used as a lap with which to grind a fly cutter, in which case the edge and a part of each side may be charged with No. 2 diamond powder.

Fig. 143 shows how the lap is to be used, by bringing it up against the sides—first one side and then the other. By having the center of the lap slightly lower than the face of the cutter a cutting clearance may be secured.

In case it is desired to form a toothed cutter as will be necessary in cutting a pinion, the method of doing so will be understood by the description now given with Fig. 144. In this case the lap shown in Fig. 144 has two holes

drilled in it as shown at A. In this figure A is a plan view;
B, an edge view from the top. After the holes are drilled
transversely through the lap, millings are made as shown
at A. This leaves a tooth b. This tooth is then bent back-
wards as indicated, the dotted lines showing the tooth before
being bent, the full ones after. The bending forms a cutting
clearance. This tooth can then be used to form a toothed
cutter.

The tooth cutter is formed in a circular blank as shown
at a, Fig. 145, then a number of holes—about 12—are drilled
in a circle as shown at b, b, b. Now millings are made run-
ning into the holes as shown by c, c. A wedge shaped piece,
f, is now driven into the milled openings which bends the

Lap

Fly Cutter

Lap
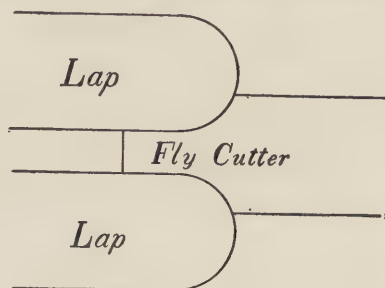
Fig. 143.

teeth backwards as at g, g, g. In performing the operation
of bending, the cutter should be clamped between flat plates
to avoid throwing the teeth out of line. Three wedges should
be provided, two of which are placed back of the tooth that
it is desired to bend. These wedges will form a resistance
that will confine the bending to the tooth marked h.

Another wedge can then be removed and placed forward
of the one just driven in, and so on, always keeping two
wedges back of the one being used. It is possible to use a
cutter of this character without bending the teeth—in fact
old time watch factories did so—but by bending the teeth a
cutting clearance is formed that will do much better work.

The circumferential speed of a cutter for cutting pinions should be about 260 feet per minute. Thus, assuming the cutter to be .6 inch in diameter, it should have about 1,700 revolutions a minute. For cutting brass wheels, the speed may be increased from 25 to 50 per cent.

As for the feed, that is to a considerable extent a matter of judgment. For brass wheels it may be as high as 40 feet per minute. For steel wheels and pinions, about one-fourth that amount would be correct. Of course it is understood that by speed is meant the rate at which the periphery of the cutter revolves. By feed is meant the rate by which it moves forward through the wheel or pinion.
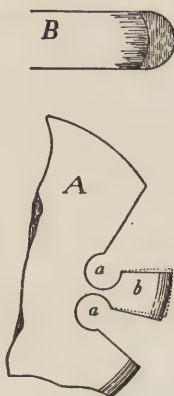
Fig. 144.

PIVOTING.—Setting a new pivot is often required in a watch of foreign make. The most difficult part of the operation is drilling the hole in the staff or arbor. To facilitate this operation the utmost care should be exercised in selecting the material for, and in making, the drill.

The writer has found from experience that a prong from a comb of an old music-box gives excellent results when made into a drill. Drill wire of any desired diameter can be procured from dealers; the best comes in short pieces and is called needle wire.

It is much easier to turn a piece of highly tempered steel than it is to drill it; consequently the watchmaker should be sure to have the staff or arbor that is to be pivoted of a sufficiently low temper to be easily drilled. A very light blue will answer. A safe and easy method of drawing the temper will now be described and illustrated.

In Fig. 146, *a* is the staff to be pivoted; it carries a wheel, *b*, near the end; *c* is a small piece of copper wire shown partly in section. This wire has a hole drilled in one end to fit the end of the arbor. The copper wire being heated in the flame of an alcohol lamp communicates the heat to the
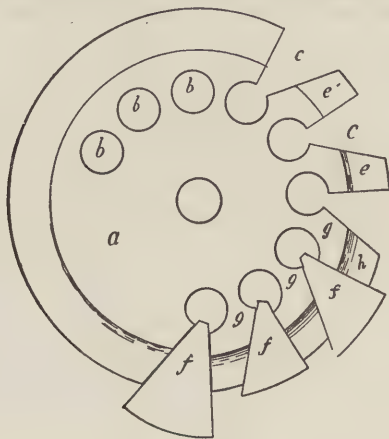
Fig. 145.

arbor without danger to the wheel, thus drawing the temper of the end of the arbor only, and the operation is entirely under control because when the temper is sufficiently drawn the wire can be immediately pulled off the staff. The arbor may now be centered and drilled.

Several kinds of tools and devices may be found on the market for centering and drilling. One of these has a spindle that provides a female center for one end of the arbor and a hollow spindle for the other end. The end to be pivoted is inserted in the chamber of the hollow spindle,

the spindle having a hole longitudinally through it. A drill is fed through this hole into the arbor. A screw collet is secured to the arbor which is rotated with a fiddle bow. There are other devices used for the same purpose, but a good bench lathe will be found quicker and better. If the arbor carries a pinion near the end to be pivoted the pinion may be held in a split chuck provided the chuck runs true. If it is a straight arbor without a pinion it can be held in the same manner. In other cases it may be shellacked in a
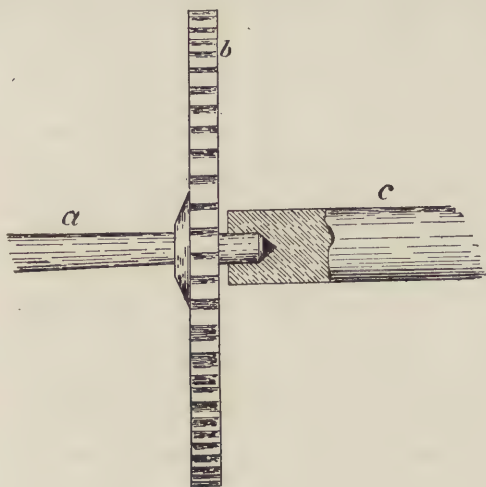
Fig. 146.

taper chuck. In this operation be sure to have a perfect female center turned in the end of the chuck. With a sharp graver, turn a countersink in the end of the arbor, being careful that no tit is left at the bottom, for if this precaution is not taken the drilling will surely run out of truth with the arbor. The hole should be drilled to a depth not less than three-quarters the length of the pivot.

The drill may be mounted in a taper in a tail spindle of the lathe and the spindle guided in a half-open tailstock, or the taper may be held in the hand provided it is main-

tained in alignment with the work—I prefer the latter method as it breaks fewer drills. In all cases a short drill is preferable to a long one. What is meant by a short drill is that a small portion of the drill should project beyond its support, which may be a supporting thimble or any other convenient method. Keep the drill sharp. Should it give evidence of not cutting sharpen it immediately. A dull drill is liable to glaze the bottom of the hole, presenting a serious obstacle. Should this occur, clean out the hole thoroughly, removing all traces of oil. Then dip a small wire in nitric acid and work it in the hole until the glazing is removed. When the hole has been drilled to the proper depth remove
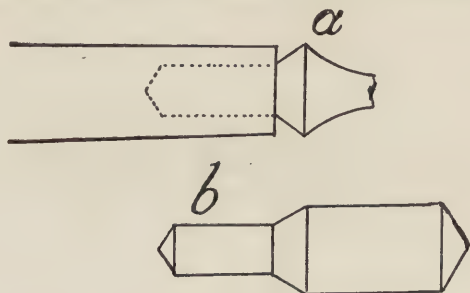
Fig. 147.

the work together with the taper chuck containing it from the lathe.

Take a piece of steel wire a little larger in diameter than the hole; harden it and draw the temper to a pigeon blue. Holding it in a split chuck turn one end to fit the hole in the arbor. It should be slightly tapered and so fitted as to leave a little driving space when inserted in the hole. Drive it in to the bottom. The length of this plug should be but a trifle greater than is necessary to form the pivot.

Now replace the work in the lathe and carefully drive the plug to place. Turn the pivot to nearly the required diameter, remembering that the smoother the turning the easier it will be to polish the pivot and the handsomer the finish.

The pivot may be polished with a rotary lap or a straight polisher.

The usual polishing compounds in use are Vienna Lime, Diamantine, and Crocus. Vienna Lime may be used with water, oil, alcohol or other liquids; Diamantine, with oil or alcohol; Crocus with oil only. Crocus prepared and used properly produces a superior black luster. Polishing blocks provided with steel plates and covers to protect them may be purchased for a trifling amount. These will protect the mixed polishing compounds from dust, and if watch oil is used for mixing the preparation may be kept for weeks without deterioration. In mixing any polishing compound with oil, it should be blended to a gritless paste with a pallet knife or some light instrument. Much depends upon the
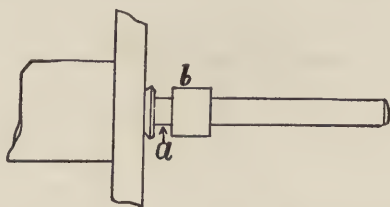
Fig. 148.

process. Put the amount to be mixed on the block and add oil sparingly; just enough to barely moisten it. More oil may be added while blending, but in no case add the dry preparation. If, while being mixed, it is found to be too thin, throw it away and start anew. Adding to the mixture when partly blended causes an inequality in the granules which is fatal to a fine polish. By using the preparation until it becomes dry on the polisher a high polish can be secured. To facilitate this, wipe the polisher lightly on the hand from time to time.

When the arbor or staff to be pivoted has a very deep oil chamber as shown in Fig. 147, the end *a* should be cut off and the plug made to include the pivot to the end of the

oil chamber. In Fig. 147 the dotted lines show where the staff is to be drilled to receive the plug, *b*.

When a full plate watch is allowed to run dry, it frequently results in cutting of the lower center pivot. In case the pivot is not cut to a smaller diameter than the cannon pinion arbor, it may be pivoted by turning the injured pivot to the size of the arbor and driving on a collar.

Fig. 148 illustrates the method of procedure. In this sketch, *a* is the pivot turned down to the size of the arbor; *b* is the collar ready to drive to place. The collar is made from a piece of steel wire drilled to a driving fit, then hardened and tempered. The outside diameter should be a little
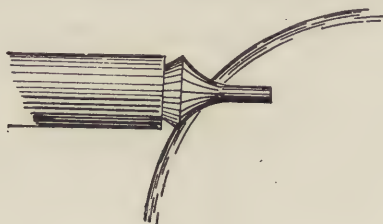
Fig. 149.

larger than it is intended to have the finished pivot. Caution should be used to have the hole in the collar the proper size for driving. The hardening usually makes the hole smaller; therefore it is better to do the final fitting after it has been hardened and tempered.

For polishing balance or other cone pivots, a rotary lap of bell metal with its center below alignment will be found an excellent device.

Fig. 149 shows how it should be used. The corner of the lap should be rounded in such a manner that it will make the cone of the pivot the desired shape. The advantage of this lap over a similar lap, with its center in perfect alignment is that the polishing lines are broken, even if the lap is not oscillated.

In using the lap in this manner its speed should be regu-

lated in accordance with the speed at which the pivot is rotated. If the speed of the lap is too great it will show spiral rings on the cone; if it is too little, circular rings will be shown on the pivot.

SIDESHAKE AND ENDSHAKE.—It is of paramount importance that all the rotary and oscillating members of a watch are given sideshake and endshake in accordance with their requirements and conditions.

The barrel arbor should be fitted rather closely, both in the plates and in the barrel. This is necessary to prevent undue tilting, which might cause interference between the barrel and the center, or other members of the train. The sideshake may be about .015 mm. The endshake in the plates about the same; in the barrel, about twice as much.

Fig. 150.

The center wheel endshake .02 mm.; sideshake .015 mm.
The same amount for the third and fourth.
The escape endshake .02 mm.; sideshake .01 mm.
The pallet arbor endshake .015 mm.; sideshake .0075 mm.
The balance endshake .02 mm.; sideshake .0025 mm.

The above proportions are intended for adjusted watches, the balance jewels of which should have olive holes.

The reason for close sideshake for the pallet arbor is to allow the pallets to be locked lightly and to minimize loss of power. The causes of which have been fully explained in the chapters on the lever escapement.

REPLACING JEWELS.—Fig. 150 shows how a jewel is sometimes burnished into a setting or plate. In this case the jewel has a chamfer on the outside and a burr is formed

from the edge of the setting, or the recess in the plate to
engage with it, as shown in the sectional view.

The method of setting jewels that will now be described
and illustrated is taken from "Jeweled Bearings," published
by Hazlitt & Walker, Chicago, Ill.

Fig. 151 shows how a jewel setting, or a recess in a plate
should be cut to receive a jewel. A is the chuck; B the
jewel setting; C the cutter. B' is an end view of the cutter
directly on the point. Observe that the face, a, of the cutter
coincides exactly with the center of the spindle. This con-
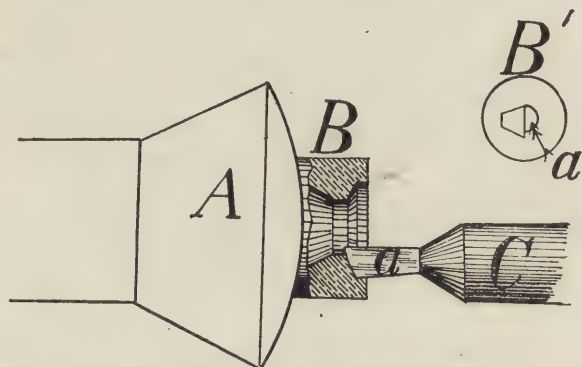
Fig. 151.

dition should invariably be secured in any cuttter used in
a caliper rest.

The jewel to be set is placed between the jaws of a caliper
rest, thus insuring the making of the recess the correct di-
ameter to fit the outside of the jewel. This is a very impor-
tant matter for the reason that if a jewel does not com-
pletely fill the recess it is very likely, when burnished in, to
be out of center with the setting. The cutter, C, is so
shaped that it cuts the seat for the jewel to correspond with
the curved side, as shown.

Fig. 152 shows the method advocated in the book referred
to, which is much preferable to holding it by means of a
mere burr.

In this case the edge of the jewel is beveled, and a pointed, chisel shaped tool — the extreme edge should be slightly rounded—is used so that it forms a strong bezel, embracing the jewel firmly. Such a jewel will never get loose. Another advantage of this method is that the jewel is much less liable to be crowded to place unevenly, thus causing its face to be out of true with the plate.

When it becomes necessary to replace a jewel that has been set directly into a plate or a bridge it is advisable to set the new jewel in a setting; then cut out a recess for it in the plate and burnish the setting to place. By doing this the workman has only the pivot hole to fit, while burnishing
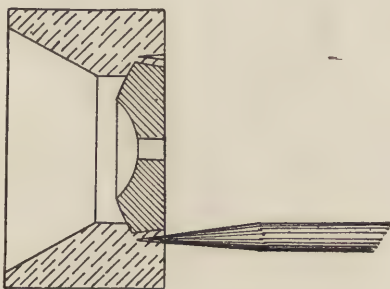
Fig. 152.

directly into the plate involves fitting the outer diameter of the jewel, also; besides which it is not always possible to raise the old burr and bring it back on a new jewel properly.

A jewel which is cracked or chipped at the hole should invariably be changed, for the reason that it is liable to cut the pivot.

When a jewel hole is found to be rough, it may be finished out without unsetting. The method for doing this is fully described in the book referred to.

CHAPTER X.

BALANCE TRUING.—Truing a balance is an operation requiring special care. It should be performed systematically, otherwise the operation will surely involve a waste of time
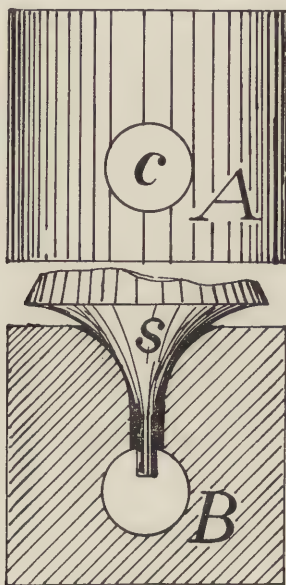
Fig. 153.

as well as a still more serious loss—unnecessary ·bending, back and forth, of the rim.

The less bending, the better. A balance may be ruined by too much bending. Repeated distortion has a tendency to disintegrate the metal. A balance in this condition is totally unfit for an adjusted watch, for the reason that the deflection of the rim is not uniform. The consequence of

this is that the balance can only be in poise at the particular temperature at which it was poised. In making the bends, care should be exercised that they are gradual ones. A sharp bend—called a kink—in a rim is somewhat difficult to remove.

THE TOOLS.—The truing caliper should be heavy enough to be rigid and provided with jeweled, or steel bearings, highly polished, for the balance pivots, or rather for the cones of the pivots. Steel is preferable for these bearings on account of its superior resistance to fracture. Fig. 153 shows how the steel bearings should be formed. A is a view of the outside; B a sectional view, with the balance cone, s,
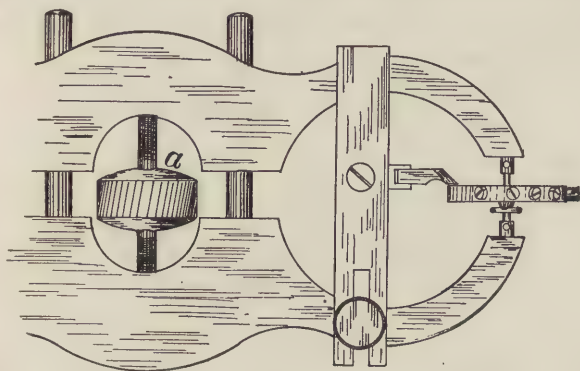
Fig. 154.

in place; c is a hole transversely through the piece containing the bearing, for the purpose of preventing the collection of dirt about the pivot. The curved bearing should be well polished and kept clean.

Fig. 154 is a partial view of a pair of calipers containing a balance, and an indicator set for truing in the flat. Observe that one face of the indicator is parallel with the face of the balance rim.

Fig. 155 shows how the jointed indicator is used when truing in the round.

The form of caliper illustrated is of the parallel type.
That is, instead of swinging on a center the jaws are sepa-
rated in a direct line, thus maintaining a perfect alignment
of the bearings for the balance pivots. This, together with
the jointed indicator, makes the caliper suitable for all sizes
of balances, which will be found a great convenience for the
repairer. Another advantage of this form is that the caliper
is always securely held to its place by the adjusting screw,
which opens and closes the jaws. This does away with the
liability of their becoming accidentally separated while the
operation of truing is being performed, in the event of
which the result might be a broken balance pivot; for it
must be borne in mind that, practically, all the operations
of truing may be performed without removing the balance
from the caliper.
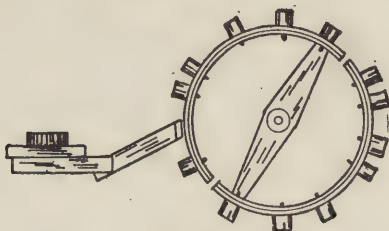
Fig. 155.

The indicator is never brought in actual contact with the
balance. For this reason an indicator brought to a point is
not suitable for determining accurately its truth. The face
of the indicator should be flat and be capable of being
brought parallel with the face of the rim. The front edge
should be an arc of a circle slightly greater than that of
the balance.

Several forms of wrenches are used in truing the rim.
Fig. 156 shows two views, each of two different forms. A
is the ordinary kind, which, as will be seen, is provided with
notches, c, to span the balance rim. B, in addition to these
notches, is slotted at a, to straddle a balance screw. A can

only be used on a part of the rim that is free from screws; B may be used among a group of screws.

Pliers are sometimes used for bending the rim where the screws are grouped. The pliers used for this purpose should be of the parallel jaw type, one jaw being perforated to receive the point of a balance screw projecting from the inside of the rim, the other jaw nicely polished and perfectly flat, to rest on the screw head as shown in Fig. 157; a is one jaw of the pliers resting on the head of the balance screw, b; c is the lower jaw—shown in section—resting against the inside of the balance rim, e, also shown in section.
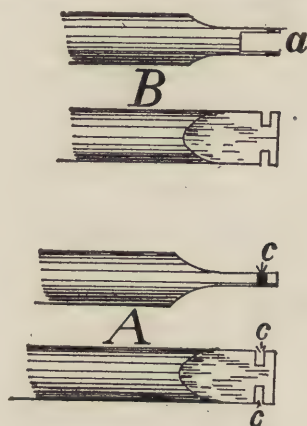
Fig. 156.

Fig. 158 shows a tool which is convenient for grasping a balance arm by its edges, at the center, while twisting it in the operation of truing the rim in the flat. The balance arm, a, shown in section, is grasped by the parallel jaws, cc, of the pliers, the jaws being notched to receive it in such manner that the staff, e, and the roller, i, are not interfered with.

It is sometimes found that the balance arms are of unequal length. In this case, if the difference is not excessive, the short arm may be stretched, which if properly done will not disfigure the balance.

Fig. 159 illustrates the method. A steel punch, a, has a face, b, formed to correspond with the circle of the inside of the rim, c. The balance is placed on a flat stub in a staking tool and the punch brought into position with its curved
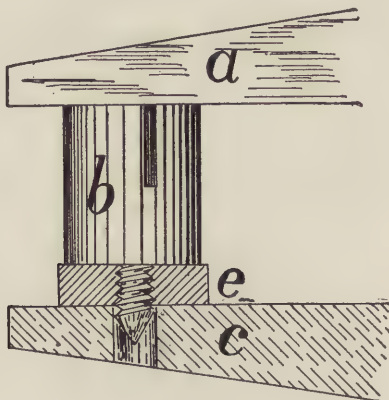
Fig. 157.

face against the inside of the rim and its beveled end on the arm, as shown. The bevel of the end should be about seven degrees. With this tool an arm may be stretched, still the punch mark be scarcely noticeable.
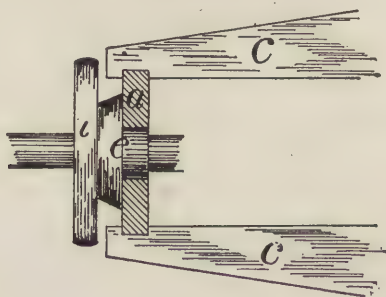
Fig. 158.

TRUING.—In balance truing, a firm rest for the hands is essential. Both hands and elbows should be comfortably

supported. The hands may be rested on the bench and the elbows supported by an apron drawer beneath it, or a small platform may be placed on the bench, affording a rest for the hands, the elbows resting on the bench.

Figs. 160, 161 and 162 are from photographs taken while the work of truing was being actually performed. These photographs were taken in the direction in which the operator looked at his work, with the calipers in his left hand, the truing being done with the right. These are presented
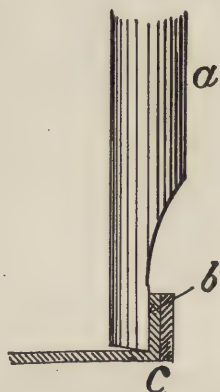
Fig. 159.

in order that the student may see just how the work is handled, thus being enabled to start right. As he acquires that skill which comes by practice, he probably will vary more or less from the directions here given. A few general rules, however, should never be varied from:

First: True the balance in the flat.

Second: True the rim in the round.

Third: True one side at a time.

Fourth: Begin at the arms, progressing thence to the cut.

In accordance with the above rules, see that the balance arms are perfectly flat; that when laid on a flat block or brought into contact with a straight-edge against the under-

side, the arms shall touch it at every part. This being seen to, place the balance in the calipers and bring the indicator as shown in Fig. 154. Try the rim at the extremity of the arms, concentrating your observation exclusively on these
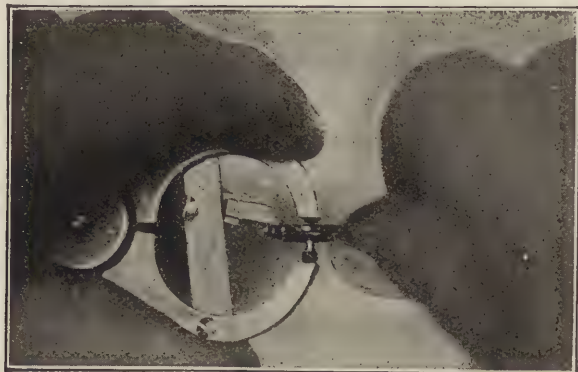
Fig. 160.

two parts, and if they are not at equal distances from the indicator bend an arm up or down according to your judgment. Do this until the heights are absolutely alike.
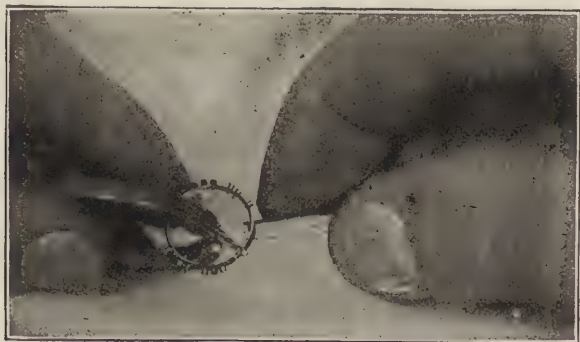
Fig. 161.

The next point to determine is whether or not the rim at these points is true with the center of the balance. To do this, bring the indicator to the position shown in Fig. 155.

In case a difference is found the shortest arm should be stretched, as illustrated in Fig. 159. When the arm has been stretched try the balance as before.

Now comes the most difficult part of the operation, truing in the flat. It is accomplished entirely by twisting the arms and rims. Upon the delicacy of touch, the judgment of the workman and the experience gained by patient practice depends the accuracy of the work.

In order to explain clearly what is meant by *twisting* the arms and rim, the operations and their effects will be illus-
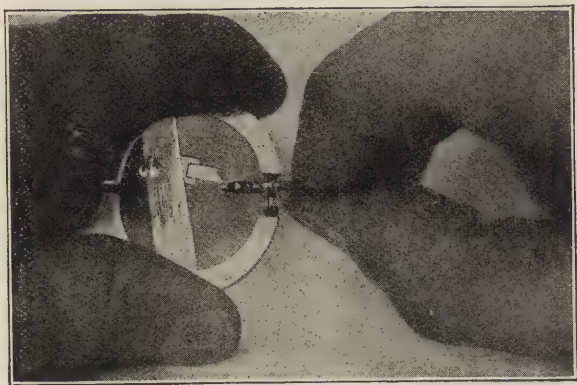
Fig. 162.

trated by drawings representing portions of balances without screws. It must not be inferred, however, that it is necessary, or even advisable, to remove the screws from the balance before truing. The writer is aware that this practice is followed by some watchmakers, but it only adds to the labor, not only by the time occupied in taking out and replacing the screws, but also from the fact that after the balance has been trued without the screws it is hardly possible to replace them without distorting the rim more or less.

The student is earnestly urged to carefully study the
directions to follow, in order that he may obtain a thorough
knowledge of the principle involved.   This mastered, the
rest is simply a matter of practice.

We will assume that a balance has had the arms leveled
and that they are of uniform length.   With the balance in
the caliper bring the indicator, c, to the position shown at a,
in Fig. 163 ; now move it until the indicator is over the point
b, at which point it will be noted that the rim has receded
from the indicator.
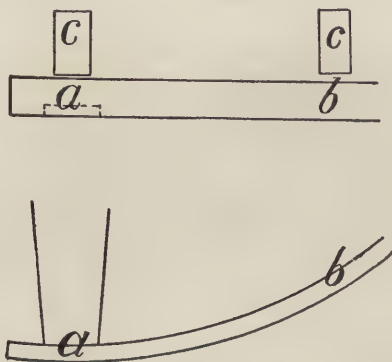
Fig. 163.

Let it be borne in mind that in Fig. 163, as in a few of
the subsequent figures, the indicator is represented in two
different positions, whereas it is intended to be understood
that the balance, not the indicator, has been moved.

Fig. 164 is a view of the same portion of the balance.
The broken lines show the rim as in Fig. 163, before it was
trued.   The full line shows it after truing.   Twisting the
arm in the direction indicated by the arrow brought the rim
up at b, to the same distance from the indicator as at a.
The manner of holding the balance while twisting the arm
is shown in Fig. 160.   We have now trued one of the rims
in the flat from the arm to the point b.

Fig. 165 shows the balance with the rim extended to d.
The rim is trued in the flat from a to b, but beyond this it
is inclined upward as shown by the indicator, its condition
shown in broken lines. We must now transfer the twisting
operation which we previously applied to the arm to the
rim. Having utilized the arm to true the balance to the

Fig. 164.

point b, any further twisting of the arm would, of course,
throw it out again. The twisting of the rim now required
may be done with the fingers or by means of the wrench.
If with the fingers the rim is grasped edgewise between the
points b and d, gently twisting to the right. If done with
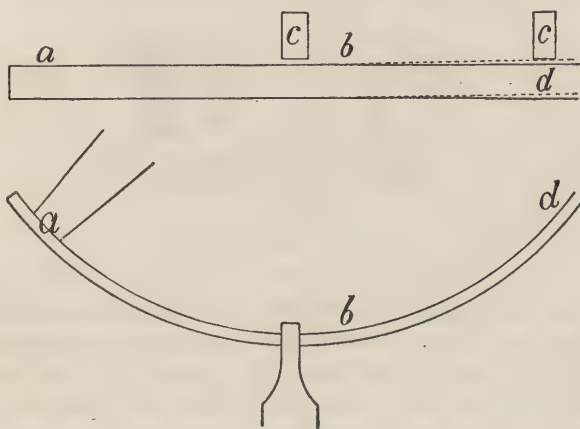
Fig. 165.

the wrench it should be placed on the rim somewhat back
of the point b and twisted in the same direction, by lifting
up on the outer end of the wrench. The manner of holding
the wrench is shown in Fig. 161. The full lines in 165 show

the rim after it has been twisted. The rim is now true in
the flat from the arm to the point d. We now proceed in
the same manner—step by step—to the cut in the rim, after
which we true the other rim in the same manner.

The balance being true in the flat it remains to true it in
the round. It is deemed unnecessary to enter into partic-
ulars in this respect. The operation is performed entirely
with the wrench, or the truing pliers. The writer prefers the
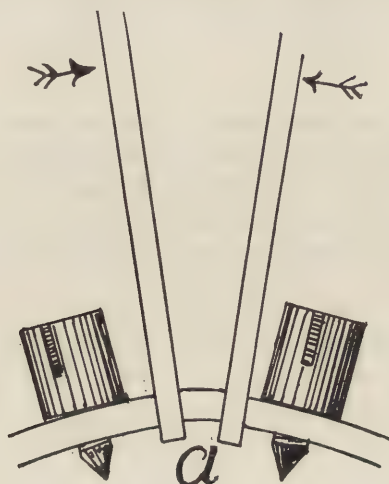
Fig. 166.

former, and has rarely resorted to the pliers. Always begin
on that part of the rim nearest the arm, proceeding grad-
ually out to the cut. Avoid bending more than is necessary.

Should you be so unfortunate as to make a kink, or to find
one, bear in mind that if the watch is a closely adjusted one
it had better have a new balance, as a kink injures the action
of the rim. The kink can be removed, however, by the use
of what we shall call twin wrenches.

Fig. 166 explains the method of using twin wrenches.
These wrenches are flat instead of round in order that they
may be brought as close together as desired. They are

shown spanning an outward kink, a. To remove it the wrenches are gently brought closer together at the outer extremity, as indicated by arrows. To remove an inward kink they are separated.

In truing in the round the rim is often thrown slightly out in the flat, in which case it should be gone over again. In fact, it should be gone over in flat and round until both are correct.

CHAPTER XI.

Poising the Balance.—For testing the poise of the balance, two sorts of devices are used—the parallel jaw poising tool and the poising calipers. Each of these has its advocates, but it is not our purpose to discuss their respective merits; excellent results are secured by the use of either. Whichever is used, it should be of the best. It is not economy to purchase an inferior tool. First-class work cannot be reasonably expected of a poorly made tool.

Parallel jaw poising tools are made with brass, steel and jeweled jaws; the best have agate or sapphire jaws. The latter is the hardest, but in no other respect is it superior to agate. In no case should the base of the poising tools be made of steel or other magnetic metal. All steel is liable to become magnetized in the course of time. For this reason it is advisable to have as little steel as possible enter into the structure of a poising tool. Steel jaws are fraught with great danger. The poising tool should be provided with means for leveling the jaws; adjusting screws in the base are excellent for this purpose.

Poising calipers are provided with jewels and endstones as bearings for the balance pivots. The hole jewel should be olived and one-fourth to one-third larger in diameter than the pivots of the balances to be used in them. Light calipers are the best for the purpose. The other tools necessary are parallel jaw pliers, with the jaws lined with cardboard; screwdrivers—called shell or clamp screwdrivers—and cutters for undercutting the screws. All of these are to be found on the market.

Before beginning to poise the balance and its staff should be critically examined. The pivots must be perfectly straight, round and polished. A balance cannot be per-

fectly poised with a bent or an out of round pivot, however slight the defect may be. See that the balance is not magnetized. This can be determined by holding a delicate magnetic compass near the rim while the balance is revolving. The effect of magnetism on a balance and hairspring will be fully described in a chapter on Magnetism, which is to follow.

The jaws of the poising tools should be perfectly level longitudinally. They should also be perfectly parallel and in alignment. To determine the latter, invert the tool on a perfectly flat block of metal, in which position every part of both jaws should contact perfectly with the surface of the block. A small spirit level may be used to level the jaws, but in the absence of this proceed as follows: Place the balance with its pivot properly on the jaws; set it revolving very slowly; if its speed increases the jaws are out of level—lowest at the end toward which, the balance is moving. Try this, adjusting from time to time until the revolutions of the balance cease to accelerate in either direction.

The proper position for the pivots on the jaws is as nearly as possible that which they occupy in the watch, which will bring them resting very near their ends.

In poising it is usual to lighten one or more screws at the heavy side. This means the side which will be downward when the balance comes to a rest. For this purpose an undercutter is generally used. An undercutter is a hollow mill. Undercutters may be bought in a variety of sizes to suit screws of different diameters.

Fig. 167 shows how the cutter and the shell or clamp screwdriver is used. In this figure A is the balance screw, B the shell screwdriver and C the cutter. It will be seen that the body, a, of the shell clasps the screwhead and serves to hold it upright on the poising cutter, while the blade, b, enters the slot, thus preventing the screw from turning in the shell. The screwhead is thus hollowed from

the under sides, leaving it, to all outward appearances, when
in the balance, the same length as before.
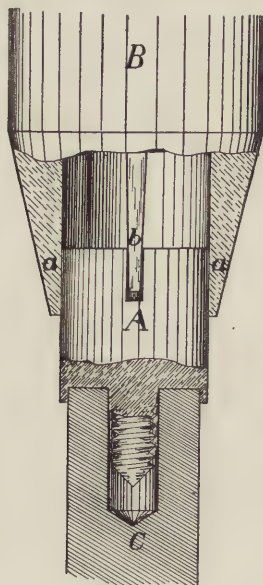
Fig. 167.

For holding a balance while removing or replacing a
screw the parallel jaw pliers, lined with cardboard, as rep-

Fig. 168.

resented in Fig. 168, are used. This prevents distortion of
the rim.

When the balance has been brought approximately in poise the finer touches are given to it with a balance saw.

Fig. 169 shows a balance saw, in which A is the handle, made of thin copper or annealed brass cut into form as desired. It is folded at the broken line and the blade held between the folds. The blade may be secured with shellac or in any other manner preferred, and should be just wide enough to enter the screw slot freely, the fine poising being secured by slightly deepening the slot and thus lightening
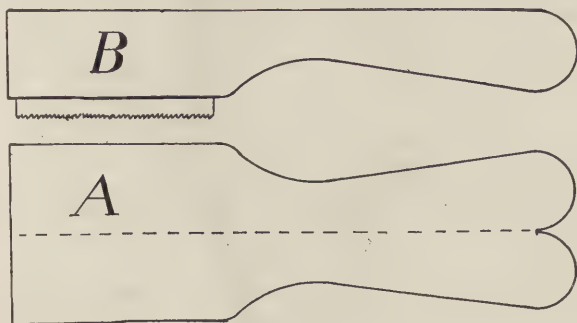
Fig. 169.

the screw by the very small amount of metal removed by the saw.

It is sometimes advisable to add weight to a balance in poising. The best way to do this is to substitute larger screws for the lighter ones, but the repairer cannot be expected to carry a sufficiently large stock of balance screws to meet all cases. The same effect can be produced by using washers under the screwheads, and if these washers are of fine gold and the exact size of the screwhead they will scarcely be noticeable. They are readily made.

Fig. 170 shows a steel punch for cutting balance screw washers.

A is the body, which may be of any convenient diameter. B should be the same diameter as the screwhead; C, a trifle

larger than the threaded portion of the screw. The punch should be undercut at b and c, the object being to make a clean cut in the gold strip. The small part of the punch

Fig. 170.

penetrates the strip first, holding it in position so that the diameter will be exactly concentric with it.

Gold rolled to a thickness of three hundredths of a millimeter will be found convenient for the washers. For a block to cut them on use box, or any other close-grained wood, cut across the grain.

CHAPTER XII.

Springing.—There are two methods of fitting a hairspring to a watch. One of these is called the vibrating; the other the weighting method. In the former a hairspring is selected of the proper strength for the balance. The second accomplishes the same result by weighting the balance to suit a given hairspring. In order to be successful by either method the workman should understand the general principles governing the action of a coiled spring as a part of the governing mechanism for a watch.

Dr. Hook, the inventor of the hairspring, enunciated the celebrated maxim: "Ut tensio sic vis"—"As is the tension, so is the power." This principle is inherent in the hairspring and constitutes its chief value as a governor for a pocket timepiece.

When a watch is perfectly in beat the roller jewel when at rest is on a line drawn from the center of the balance staff to the center of the pallet arbor. This is called "the line of centers."

Let us suppose that a balance—perfectly in beat—is started from the line of centers. The first impulse delivered by the escapement moves the balance through a short arc, producing a certain amount of tension in the hairspring. The tension thus set up is sufficient to carry the balance to an equal distance on the opposite side of the line of centers. In passing to this point it receives another impulse which adds to that power and carries the balance still further, and so on; the extent of the vibrations increasing with each impulse, until it reaches the maximum. The reason that the extent of the arcs of vibration does not increase indefinitely although the impulses continue is that the balance meets with constantly increasing resistance from various causes; resistance from impact of the jewel pin against the fork

and the escape wheel tooth against the pallet stone; resistance from the friction from the balance pivots in their jewels; the roller jewel against the fork; the pallets and escape teeth, and other causes. The greatest, however, is the resistance of the atmosphere to the rim of the balance and its screws. When the point is reached where these various frictions overcome the force of the impulse the balance comes to a rest, and the power acquired by this tension of the hairspring reverses the motion of the balance and returns it to an equal distance in the opposite direction.

As the impulses decrease in force the extent of the vibrations decrease in the same proportion until, when the watch runs down, they cease altogether.

The owner of a watch may say, "My watch never stops except when I let it run down." The fact is, a watch stops an astonishing number of times. The entire mechanism much stop at the end of each vibration of the balance—432,000 times every day.

INSPECTION.—In selecting a hairspring for a watch, see that the convolutions are perfect; that it forms a true spiral with its coils a uniform distance apart. Any error in the evenness of the coils can be readily detected by taking the spring by its center coil, with the tweezers, using a piece of white paper as a background, and tipping the spring at different angles. If the coils are not perfectly uniform, uneven streaks or patches of light will be apparent. Now test it for flatness. To do this hold the spring vertically, looking across the coils. If the spring is true the edges of all the coils will lie in the same plane.

The diameter should now be determined. If the spring is to be Bregueted, more or less latitude may be allowed in its diameter; but when the spring is to be a flat one, its size will be limited. It must not be of a greater radius than the distance from the balance jewel hole to the regulator pins.

Fig. 171 illustrates the method of determining the correct diameter for a flat hairspring. A is an arbor, which may be a piece of soft steel wire. It should be slightly tapered toward the end, a, upon which the hairspring, B (which
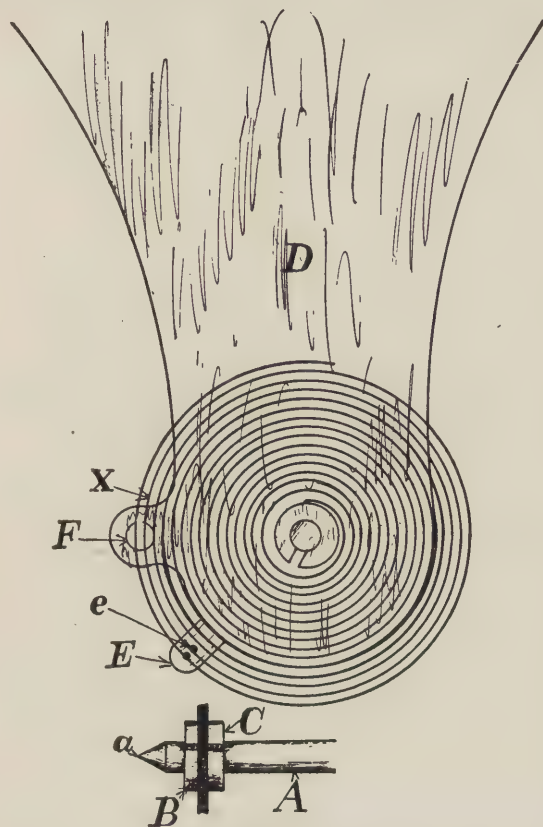
Fig. 171.

may be with or without a collet), is placed. D is the balance cock, with the regulator, E, and the stud, F, in position. The point, a, of the arbor, A, is placed in the cup of the balance jewel hole and the hairspring rotated until a

coil comes directly over the inside regulator pin, e. This is the point where the hairspring is to be held while vibrating. That portion of the spring beyond the point X will ultimately be broken off, but it is better to allow it to remain until after the vibrating has been done. If, in the process of vibrating, the spring should be found to be too strong, select a weaker one. The reason for this is that the spring in no case must be larger than called for by the method described. It may be somewhat smaller. A spring too large will be out of center when the balance is at rest. A small spring may be brought to center by separating the outer end to a somewhat greater distance from the adjacent coil. It is not necessary to collet the spring before determining its diameter. An arbor large enough to fill the center of the spring may be used by pushing it on the naked arbor.

VIBRATING.—The proper strength of a hairspring may be readily determined by the process known as vibrating. Vibrating is done by two different methods—sight and sound.

To vibrate by sight, an accurately timed balance and spring are used as a standard. These are usually mounted in a device called a vibrator. One kind of vibrator is a plate provided with an arm that holds the balance with its spring distended as in Fig. 172. Another kind has a balance mounted in jewels, as in a watch. In using the former, the balance being vibrated is held by the side of the standard; in the latter it is held directly above the standard, a watch crystal intervening between the two. In either case the balances should be started vibrating in unison and when a difference manifests itself the position at which the spring is held by the tweezers, or clamp, may be changed to correct the difference, moving it so as to decrease the length of the spring to make the balance vibrate quicker; or to lengthen it to make it vibrate slower.

It should be borne in mind that the point grasped by the tweezers is to be the central location for the regulator pins,

and that a sufficient amount of spring beyond that point should be left for securing it in the stud.

Instead of mounting a balance especially as a standard, a watch may be used for the purpose—always provided that its balance gives the proper number of vibrations. At the present day there are but two numbers for the vibrations of balances. They are called 18,000 and 16,000 trains. The
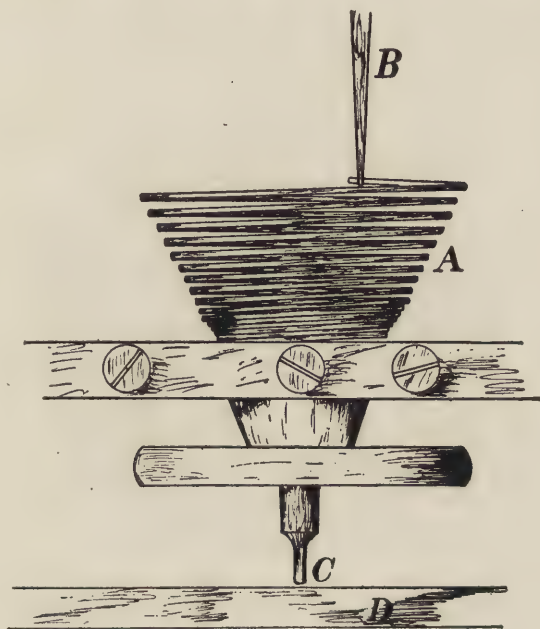
Fig. 172.

former gives 18,000 beats per hour—300 per minute; the latter, 16,200 per hour—270 per minute.

Vibrating by count is the oldest method and is still pursued by some workmen. In using this method, no standard balance is necessary nor is it necessary that the watch used should give the same number of vibrations as the watch being sprung, although it is better to have this condition exist.

A clock, beating seconds will answer. The usual method of holding a spring to vibrate by count is illustrated in Fig. 172. The clamp, or tweezers, B, holds the spring so as to bring the lower pivot of the balance staff just clear of the base of the vibrator, which may be glass or enameled metal. The balance is set in motion. As the spring contracts when the balance vibrates in one direction the pivot is lifted from the plate and as it expands when it starts in the opposite direction the pivot drops upon the plate with an audible

Fig. 173.

sound that renders the vibrations easily counted. As the sound occurs at alternate vibrations it simplifies the counting. For an 18,000 train the number of strokes made by the balance pivot on the plate will be 150 per minute. For a 16,000 train it will be 135.

In vibrating it will answer the purpose to count the vibrations for one-half minute until you secure a close approximation, when the time may be extended to a full minute.

After the balance is placed in the watch it may be run first for one hour and after the necessary alteration be run for 24 hours.

A preliminary trial of a hairspring may be made without colleting it. Fig. 173 illustrates the means employed. A is a small piece of beeswax into which the top pivot of the staff is inserted and in which the end of the inner coil of the hairspring is imbedded. To prepare the wax, take a minute piece and roll it into a ball, then flatten the ball. The size of the piece should be such that when flattened it will be about the thickness and diameter of a hairspring collet, for which it forms an excellent substitute. First imbed the inner end of the coil in the beeswax, then push the balance pivot into its center.

When the number of vibrations for the balance being sprung is not known they may be determined as follows: Count the teeth in the fourth wheel and the leaves in the escape pinion. Divide the former by the latter. If the quotient is ten the train is 18,000; if it is nine, the train is 16,200—called 16,000.

TRUING THE HAIRSPRING.—In truing a hairspring, all bending necessary should be performed between the point where it enters the collet and the first quarter coil.

First, true the spring in the flat. In this case the bending should be confined as much as possible to the elbow near the collet.

Fig. 174 illustrates the proper method. When a spring is tilted up or down, as at A, it should be brought to place by pressing at the point a. When it is tilted, as at B, the pressure should be at b. It will be observed that the figure A and B represent springs tilted out of flat in different relations to the pinning point. A is tilted up one-quarter round from the pinning point, and of course down at the opposite side. B is tilted up one-half way round from the pinning point. In these drawings the tilting is exaggerated. When

it is as much as shown the spring should be unpinned from the collet and repinned to a closer approximation of truth in the flat. The reason for this is to avoid excessive bending. The less bending of a hairspring, the better the results in time. A spring may be utterly ruined by too much bending. A hairspring should never be trued in the flat by twisting a coil in the manner shown at C. Close adjustment is
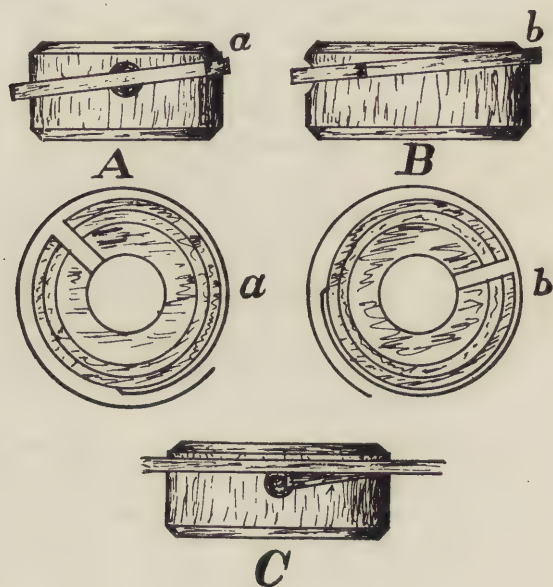
Fig. 174.

an impossibility in a hairspring thus treated, the reason being that the portion of the spring below the body exerts an influence that causes the spring to rock up and down quite noticeably when the balance is at full motion. This rocking and distortion of the spring materially affects isochronism.

Truing a spring in the round is a much more difficult operation, requiring considerable practice; indeed, it requires an education of the eye to determine the difference between

a spring that is perfectly true and one that is nearly so, and
still more practice to determine in what direction the great-
est difference exists. The nicety of perception and judg-
ment required for this purpose is more difficult to acquire
than is the skill used in truing. Truing the spring in the
round, as has been previously mentioned, should be done by
bending as near the inner end as possible, never extending
beyond the first quarter coil.
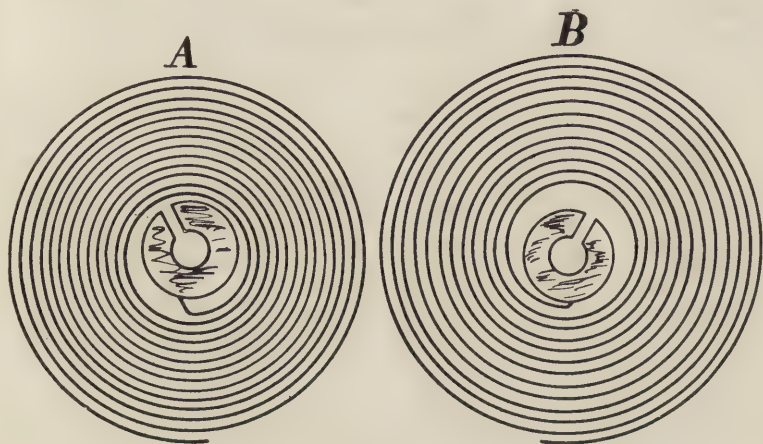
Fig. 175.

Figs. 175 and 176 illustrate the conditions generally exist-
ing and the method of treatment. If the spring is pinned
to the collet as at A it cannot be trued in the round cor-
rectly. If pinned as at B, although the center is a trifle
large, it may be nicely trued beyond the first quarter coil.
C shows how this is accomplished. It will be seen that the
necessary bending to bring the spring true was done mainly
at a point somewhat less than one-quarter way from the
point of pinning. The correct pinning of the spring shown
at B is illustrated at D. The same is virtually true of the
spring shown at A. These two springs when pinned as
shown at D would require very little truing in the round.

What has been said of the manner of pinning springs
having large centers applies to ordinary unadjusted work.
Hairsprings used on adjusted work are sometimes provided
with inner terminal curves which require a spring with a
larger center than would be otherwise necessary. The con-
sideration of this matter, however, will be taken up more
fully when the subject of adjustment is treated.

The operations of truing, just described, should be per-
formed with the hairspring in place on the balance, the bal-
ance in the calipers. The succeeding operations must be
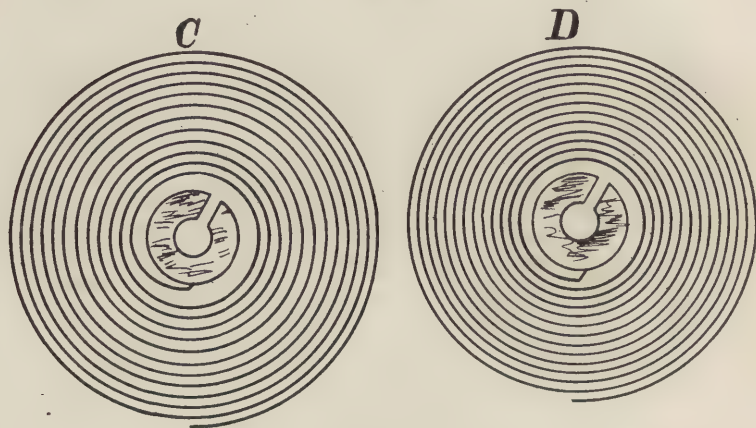
Fig. 176.

done with the balance in the watch. They consist of level-
ing, circling and centering, which are performed in the
order named.

LEVELING.—Leveling is that adjustment of a spring that
brings it flat and at right angles with the balance staff. That
is, looking across the spring, it will not appear either con-
cave or convex, but will present the appearance of a per-
fectly flat plane, parallel with the top of the balance and
necessarily at right angles with the staff.

MANNER OF PROCEDURE.—Bring the hairspring stud to a position that will insure the outside coil where it is pinned to the stud being at the same height as the inner coil where it is pinned to the collet. The spring may now be at an angle other than a right angle with the staff, as shown in Figs.

Fig. 177.

177 and 178. To bring it level—at right angles with the stud—more or less bending may be necessary, which should always be done as near the stud as possible.

Figs. 177 and 178 are designed to illustrate how the bending should be done. In both these figures A is the balance cock, B the hairspring, C the stud, D the balance. The stud

Fig. 178.

is located at the side of the balance cock. In Fig. 177 the hairspring is canted longitudinally with the cock, in which case an upward pressure should be applied to the outer coil near the stud and to the left. This will bring the point b up and the opposite side of the spring down. In Fig. 178 the spring is canted transversely with the cock, in which case a slight twist should be given at the point c, close to the stud.

Fig. 179 shows a tool, very easily made, which is much more convenient than the tweezers for leveling a hairspring. It may be made of steel wire about .075 inches in diameter and 3½ inches long. The handle, A, and the shank, B, are round; the latter is flattened at C and slotted at D, the slot being just wide enough to span a coil of the hairspring. Placed with the slot, D, spanning the wire near the stud, as at F, it is used as a wrench to twist the spring. The advantage of this little tool is that it grasps the hairspring unyieldingly, thus insuring a certainty as to the amount the spring is twisted, whereas, when the tweezers are used for
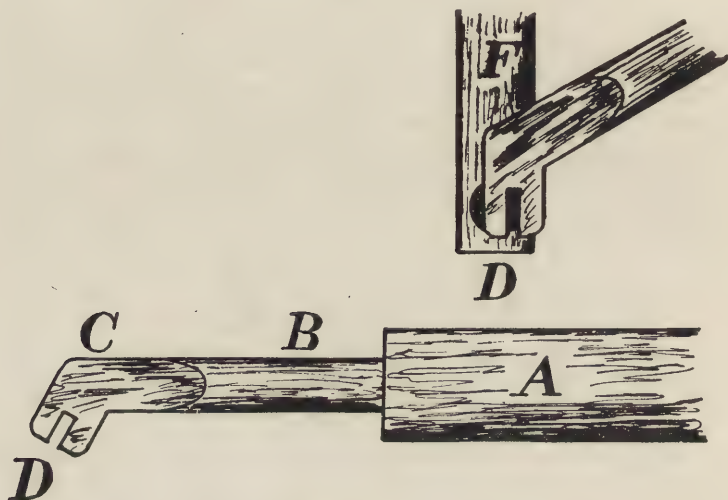
Fig. 179.

the same purpose there always exists an uncertainty. Besides, this, when it is desired to throw the spring downward opposite the stud it is generally necessary to lift off the balance cock and balance in order to do so, when tweezers are used for this purpose, as the edge of the cock will prevent the tweezers from being tilted over when the spring is grasped from the upper side. In leveling a spring it may be neces-

sary to raise or lower the stud in order that the spring shall form a perfect plane at right angles with the balance staff. Even the slightest variation from this condition will cause a rocking of the hairspring when the balance is in motion.

CIRCLING.—The next operation is circling—sometimes called training. To circle a spring the regulator pins should be but slightly separated. That part of the spring that is included in the full sweep of the regulator should be formed
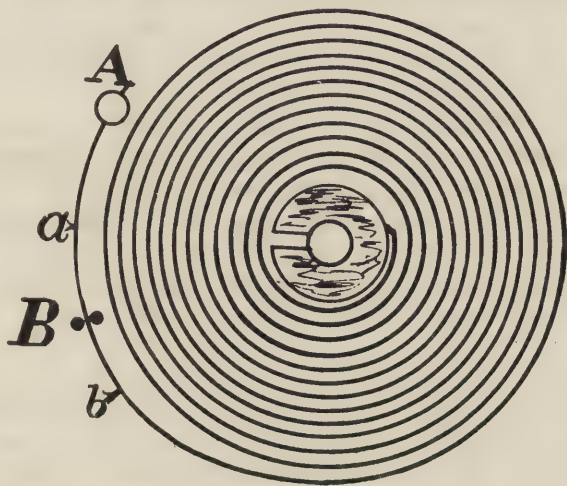
Fig. 180.

into an arc of a circle with the balance pivot as its center. In other words, with the balance at rest we should be able to move the regulator through the entire sweep of its index without either regulator pin coming in contact with the spring. This condition is essential in securing a close rate.

Fig. 180 shows the condition to be secured. A is the stud, B the regulator pins, a and b mark the limits of the arc through which the regulator pins may be moved without their touching the spring. When this condition has been

secured the regulator pins should be closed up, leaving them just a sufficient distance apart to move freely on the spring without cramping it.

CENTERING.—We are now ready for the final operation—centering. This consists of forming the outer coil so that the body of the spring shall be perfectly centered with the staff, as shown at Fig. 180. It will be seen that the outer coil of the spring forms an arc of a circle from the stud, A, to the end of the sweep of the regulator, d, from which point the outer coil of the spring is slightly curved in such a manner that when at rest the center of the collet will register perfectly with the cock jewel. The last quarter of the outward coil is now a greater distance from the second coil than the other coils are from each other, a condition which invariably exists in a flat spring.

In Breguet springing, the spring may be vibrated in the flat precisely as described for a flat spring and the over-coil formed afterward. A full description of the principles involved and the method to be pursued will be found in the chapter on Isochronism.

TIMING.—The watch is now ready for timing. Should it run slow the hairspring may be taken up. A flat spring may be let out in case the watch runs fast, but when a watch with a Breguet spring runs fast beyond the control of the regulator, the balance should be weighted. For this purpose washers may be placed under the balance screws, but those usually found on the market are not to be recommended. Washers should always be used in pairs—one each under opposite screws. Washers punched from gold will be found more effective and less conspicuous than those punched from other metals. Gold, though suggestive of cost, will in this case be inexpensive for the reason that the amount used is so minute. A strip of gold 24-kt. fine, about .05-mm. thick, may be used for the washers. A tempered steel punch

and a block of boxwood, or other close grain, hard wood will be found suitable to lay the gold strips upon while punching washers. A steel punch for punching washers has
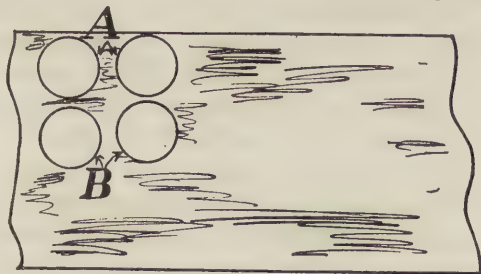
Fig. 181.

been described and illustrated in Fig. 170 in the chapter on poising the balance.

Fig. 181 shows how the washers should be cut from the strip. Two pairs are here represented, A and B. These
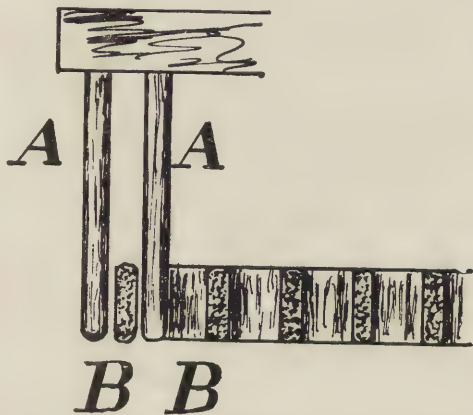
Fig. 182.

pairs should be kept separate and used under opposite screws.

A fruitful source of trouble in a flat hairspring is the liability of two coils getting between the regulator pins, and

of one or more coils getting outside both pins. This can be entirely overcome by following the directions here given.

A A, Fig. 182, are the regulator pins, B B the hairspring coils. The regulator pins are shown in full and the coils of the hairspring in section. It will be observed that the regulator pins are rounded at the ends. This is done for two purposes: to secure them against burr and to prevent the possibility of the hairspring catching. The ends of the pins should not be allowed to project below the under side of the hairspring, as shown in the drawing, and the pins should be sufficiently close together to prevent the possibility of more than one coil of the spring getting side by side between them. Should one or more coils of the hairspring, owing to a sudden jar, be thrown over the ends of the regulator pins, they could find no lodgement there and would be immediately returned to their proper place.

CHAPTER XIII.

MAGNETISM.—Magnetism is a relentless and insidious enemy to watchmakers. It cannot be resisted or rendered harmless. The only way to avoid its malign influence is to keep out of its reach. The worst of it is that you are never sure when the watch is out of danger.

Electricity and magnetism are sometimes confused. They are not identical. Electricity may be made to produce magnetism and magnetism to produce electricity, which are two different forces.

Electricity may be conveyed from location to location by means of wires, and it is possible by insulation to confine it to a great extent to the wires used in conveying it. Magnetism cannot be insulated. Such substances as glass and india rubber which obstruct the passage of electricity to a considerable extent are no obstruction whatever to the passage of magnetism. Magnetism is therefore an insidious enemy, the only safety being to keep out of its reach. A moderate flow of electricity through a watch is comparatively harmless. The worst it can do is to cause the breakage of the mainspring, whereas the presence of even a slight amount of magnetism is highly detrimental.

There are three ways in which magnetism may be imparted to steel: By contact with a magnetized metal, by being brought within an electro-magnetic field, and by concussion.

Every magnetized body is surrounded by what is known as magnetic fields. When a piece of steel is magnetized it possesses at least two poles—sometimes more. Each pole has what is termed a magnetic field. That is, there is a certain space around the pole through which its magnetic attraction extends. This attraction is stronger at the pole,

and becomes weaker as the distance increases, until it is so weak that it cannot be detected. The distance is proportional to the strength of the magnetism. When a piece of carbon steel is brought within a magnetic field it becomes a permanent magnet, the strength of which is dependent upon the strength of the magnetic field into which it is brought and its proximity to the magnet, which reaches its maximum when in actual contact. When a piece of iron which has been decarbonized is brought within a magnetic field it becomes temporarily magnetized only. When it is withdrawn from the field the magnetism disappears. If we wind a number of coils of insulated wire about a cylinder of pasteboard and connect the ends of the wire with a battery or other source of electricity we have what is called a solenoid. Any carbon steel brought in proximity to it will become magnetized permanently. Any iron, containing no carbon, brought within the magnetic field will only become temporarily magnetized. In either case the magnetism is produced by induction from the solenoid. When a current of electricity is passed through the wire forming a solenoid, the magnetic fields will be positive at one end and negative at the other. This applies to what is known as a direct current, which is a current passing in one direction.

When this current is what is known as an alternating current it changes its direction alternately in opposite directions, which of course, changes the poles. This it does with great rapidity—in ordinary electric lighting systems—a 60 cycle current, which means that it gives 120 changes every second. When a piece of steel is inserted in the solenoid and the flow of electricity is suddenly cut off, the steel will be found strongly magnetized, its poles being in conformity with the last half cycle sent through the wire. When a piece of steel is inserted in the solenoid through which an alternating current of electricity is passing, and is gradually withdrawn, it will be polarized twice for every

cycle. This polarization will be reversed twice, changing the poles from one end to the other twice every cycle—120 times a second. Thus it is magnetized, demagnetized and remagnetized again in rapid succession while the piece is being gradually withdrawn. The consequence of this is that each successive polarization is weaker than the preceding one, until when withdrawn entirely from the field the magnetism has disappeared.

Another manner in which steel may become magnetized is by concussion. When it is thus brought about, the location of the poles will depend entirely upon the position the steel occupies toward the earth. If we place a bar of tempered steel in a perpendicular position, it becomes a temporary magnet by induced magnetism from the earth. This can be easily demonstrated. Holding a bar of unmagnetized steel in an upright position and bringing a magnetic compass to its lower end, it will be found that the south pole of the magnet is attracted. Moving the magnet to the upper end of the bar the north pole will be attracted. Reverse the bar and the north pole will still be found at the top, the south at the lower end. While held in this position, if concussion is brought about by hammering or otherwise, the poles will become fixed, and the magnetism will be permanent.

This is why watchmakers' tools, especially punches become magnetized. An important lesson to be learned from this is that punches should be examined from time to time in order to detect magnetism if present, and if present, they should be demagnetized. Another important matter is to frequently test tweezers, which, because of their frequent contact with hairsprings, should be closely watched.

A watch strongly magnetized is worthless as a time piece. A few illustrations accompanied by specifications are given to show how and why magnetism disturbs the rate of a watch. When a watch is brought within a magnetic field

the mainspring becomes polarized. Whatever position the mainspring happens to occupy at the instant that the magnetism is imparted to it, the poles will assume positions at opposite sides as shown in Fig. 183. There are then two poles to each coil and the location of these poles in the spring becomes permanent, regardless of the position that it may subsequently assume. In other words, the spring possesses a multiplicity of poles, north and south alternating. If the spring is straightened out and moved from end to end in proximity to a magnetic compass, the succession
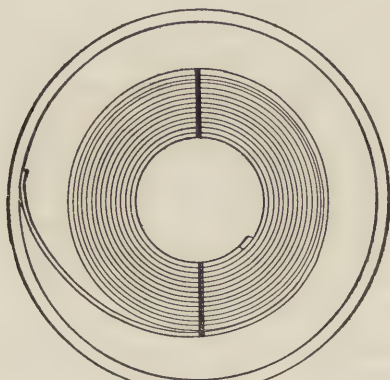
Fig. 183.

of north and south poles will be clearly indicated by the movement of the needle.

Take two pieces of steel wire each two inches long by 1/10th inch diameter. Holding them side by side with their ends even, magnetize them. Still holding them side by side bring them, radially, in proximity to a magnetic compass until one of its points is attracted. Remove one of the pieces and it will be found that the attraction has noticeably been decreased. Reverse the wire that was removed and bring it side by side as with the other wire, as before. You will now have a north pole of one wire and a

south pole of the other presented to the magnet. It will be found that these opposite poles will neutralize each other and will not attract the compass.

Fig. 183 shows a spring that has been magnetized when it is wound close about the barrel arbor. It will be observed that the poles are located radially from the center and directly opposite. All the North poles are indicated by black marks and are in line at one side. The South poles are indicated by crosses and are in line at the other side. They being located thus, the combined magnetic fields of each set of poles makes the attraction of the maximum strength. As
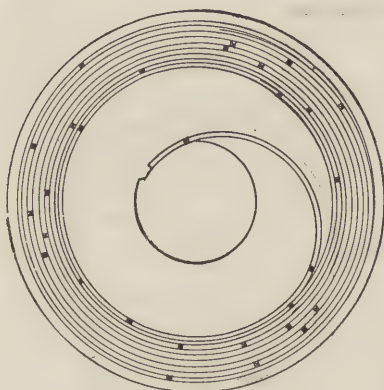
Fig. 184.

the spring unwinds, the locations of the poles change with respect to each other. The North and the South poles become intermingled, until at last, when the spring is completely down, their positions will be as shown in Fig. 184.

In this condition the poles are so intermingled that the magnetic fields are very weak. We therefore have a constantly changing magnet acting upon the watch balance as the spring unwinds. The above is the principal cause of the erratic performance of magnetized watches.

A simple experiment may be tried to demonstrate this. Take any strongly magnetized watch, remove the balance and pallets. Remove the hairspring from the staff and replace the balance without it. Now wind up the mainspring and let the train run slowly down, holding the watch in a horizontal position. The balance will be found to move back and forth in response to the changes of magnetic attraction as the position of the poles in the mainspring becomes diversified.

In addition to the varying attraction of the mainspring, the positions of the poles in the winding works are changed whenever the watch is wound, which also causes a variation in their attraction.
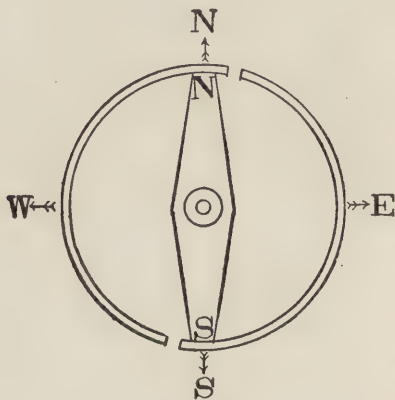
Fig. 185.

A magnetized balance, even though no other part of the watch be magnetized, will cause a variation of rate. This is due to the earth's magnetism, which affects the balance exactly as it does a magnetic compass. To demonstrate this effect, poise a balance perfectly, then magnetize it. Holding it in a horizontal position, in a pair of jeweled calipers, it will behave like a magnetic compass, a certain part pointing towards the North.

Let us assume that the poles are at the ends of the arms as in Fig. 185. When the balance is in a horizontal position, the north end will point North and the south end South, as indicated in Fig. 185. In Figs. 185, 186 and 187, the points of the compass are indicated by the letters N, S. E, W, located outside of the balance, and the direction indicated by arrows.

With the balance in a horizontal position as in Fig. 185, the north end of the arm will point toward the North and the south towards the South.
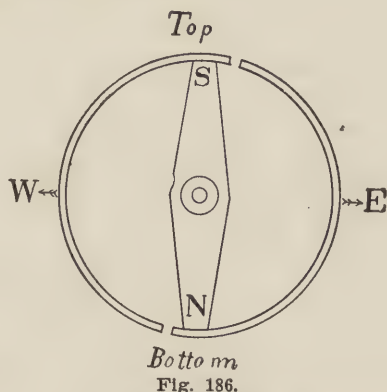
Fig. 186.

When the balance is held with its staff pointing north and south, the balance will assume the position shown in Fig. 186, with the north end down.

When the balance is held with its staff pointing east and west, it will assume the position shown in Fig. 187.

The reason for these peculiar changes is that the earth's magnetic poles are not located at the surface, but some distance toward the center. The geographic and the magnetic poles therefore, do not coincide.

The earth's magnetic poles, however, are approximately equi-distant from the equator. A poised magnetic needle assumes a horizontal position at the earth's equator. As we proceed northward the North magnetic pole's distance con-

stantly decreases and that of the south pole increases. This
causes a deflection of the needle, the north point of which is
attracted more strongly than the south, until when we reach
the north pole the needle will stand perpendicular.

It is only when the balance is held in the position shown
in Fig. 187, that it can assume a position pointing approxi-
mately to the North pole. It would point directly were it
not for the attraction of the South pole. In Figs. 185 and
186 it is prevented from pointing directly toward the pole
by the restraint imposed upon it by the position of the bal-
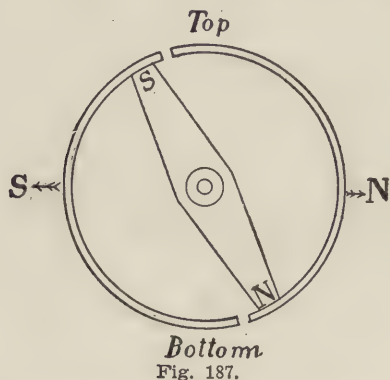
Fig. 187.

ance staff. The nearest approach that it can assume is that
shown in the illustrations referred to.

A magnetized balance is thus affected by the earth's mag-
netism, producing the same effect on the rate of a watch as
if the balance was actually out of poise from the attraction
of gravity.

DEMAGNETIZATION.—The best method for removing mag-
netism from a watch is by the use of a solenoid.

There are several forms of these devices on the market.
They are generally so constructed that the current may be
taken from an ordinary lamp socket carrying 110 to 220
volts current. If the lamp current is direct, the demag-

netizer must include means for transforming it into alternating current of at least 60 cycles. If the current is alternating, it may be carried directly to the solenoid. Instruments for demagnetizing are to be found on the market, including the transformer.

In presenting the watch to the demagnetizer, hold it within the solenoid, as centrally as possible. Turn on the current. Slowly withdraw the watch, keeping it central with the opening. As it emerges, turn it $\frac{1}{4}$ way round. That is, assuming that the watch is held horizontally by the pendant, turn it either pendant right or pendant left, continuing to withdraw it while so doing. Continue this withdrawal until the watch is distant from the demagnetizer at least 36 inches. If the first trial fails to remove all traces of magnetism repeat the operation.

It sometimes happens that the watch has been exposed to such a strong magnetic field that treating it as a whole will not remove its magnetism, although it is rarely that a voltage of 220 will fail. Should it fail, take the watch apart and treat the pieces individually.

In demagnetizing watch tools insert them longitudinally in the solenoid and withdraw them directly. Do not turn them $\frac{1}{4}$ way round as you would a round piece like a watch. When tweezers are to be demagnetized, bind the points together with brass wire or string. In withdrawing them from the solenoid, do so blunt end outward.

For detecting magnetism in a watch use a very small, sensitive magnetic needle. A simple little device, to which I have given the name "Magnetic Detector" may be made as follows: Procure a vial such as is used for medicine. Let it be one inch long by one-quarter inch in diameter. Insert a brass wire through the cork. Take a piece of hairspring about 1/10th inch long. Select from floss silk as fine and as straight a fibre as you can. Secure one end of the fibre to the piece of hairspring and the other end to the brass

wire. Shellac dissolved in alcohol may be used to attach the fibre. See that the vial is perfectly clean inside. Insert the fibre with a piece of hairspring at its lower end into the vial. Adjust the piece of hairspring to a point near the bottom of the vial but sufficiently high to clear it. The wire through the cork will afford means for the adjustment. Cut off that portion of the wire projecting above the cork and seal the vial. Bring the vial within a strong magnetic field. You will then have a delicate magnetic needle. Cut a circular piece of paper about twice the diameter of the vial and secure it on the bottom.

Fig. 188 shows the instrument complete.

Fig. 188.

In using it have the watch to be tested, running. Stand the detector on the balance cock dome. The slightest amount of magnetism will be indicated by a tremor of the needle. A greater amount will cause a violent agitation.

CHAPTER XIV.

ADJUSTING.—Some one has said, "An adjusted watch is a watch in perfect order." This is literally true, for that is what adjusted means; what it attempts to secure.

The word adjust is derived from the Latin words "ad" and justus: just right. This expresses it. When a watch is just right it is what we call a naturally adjusted watch, and requires no alteration by the adjuster.

The process of adjustment may be divided under three heads: temperature adjustment, isochronal adjustment, and position adjustment.

Temperature adjustment—technically called compensation—is the simplest of the three. For this adjustment definite rules may be laid down which almost invariably produce predetermined results, and it is the only one of the three of which this can be truly said.

CAUSES OF TEMPERATURE ERRORS.—All metals used in watch construction expand with heat and contract with cold. The proportion in which these changes take place is called the coefficient of expansion. When we say that soft steel has a coefficient of expansion of .00000599 it means that a bar of steel will elongate that percentage of its length for each degree of rise in temperature. The coefficient of brass is .00001037. Therefore brass expands 7/10 more than steel. There is also another effect that heat produces on most metal; in fact, on every metal of which I have any knowledge, except nickel-steel. It renders them less rigid; more easily deflected when heated.

In case the student desires to make demonstrations of the laws governing expansion and elasticity of metals, a simple device shown in Fig. 189 may be used.

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Take a sheet of brass of any convenient thickness and about six inches long by two inches wide. In case it is not convenient to procure brass, sheet iron or even tin will answer. Drill two small holes, A and B, about one-fourth inch apart. Insert two pins to form a support for a piece of watch mainspring, C. Allow the end of the mainspring to project beyond the plate as at D. Provide a small weight, E, that may be slid over the projecting end of the mainspring. The spring should not be fastened rigidly to the plate, but simply allowed to rest under pin A and over pin B. Mark a diagonal index, F, near the right hand end of the brass plate. This device may be used to demonstrate several laws governing the rate of watches as it changes with changing temperature, as will be explained later on.

Berthoud, in 1773, published the following proportions as the result of his experiments on the causes of change in rates in different temperatures. For a variation of 6 minutes and 33 seconds, in temperatures of 32 and 92 degrees Fahr. for a period of 24 hours. Loss from elastic force of spring, 5 minutes and 12 seconds; from elongation of spring, 19 seconds; from expansion of balance, 1 minute and 2 seconds. It is assumed that he used a plain balance, but we have no details of the test, nor does he explain how he made his deduction. His statement, however, was accepted without question and continued as authority for many years. This places the variation from expansion of the balance at between 1/5 and 1/6 of the total error, provided the balance used was of steel.

A watch with a brass balance and a high tempered steel hairspring, if regulated in a temperature of 40 degrees Fahr., will, when run for 24 hours in a temperature of 90, lose about 6 minutes, or 15 seconds per hour. Without troubling the reader with the mathematical calculation by which the result was arrived at, suffice it to say that taking the coefficient of the expansion of the brass at .00001037, the loss

from expansion of the balance would be about one-eighth
of the total—about 47 seconds; the remaining 5 minutes
28 seconds would of course be due to other causes; mainly
the loss of elastic force of the hairspring, or rather its loss
of resistance to flexure. I question whether elongation of
the spring has anything to do with it. It is thus seen that
in adjusting a watch to temperature, by whatever method,
the adjustment must correct not only the error produced
by expansion and contraction of the balance, but about eight
times as much for the error produced by the hairspring.

No satisfactory reason has ever been given in explana-
tion of the effect that heat produces on the hairspring so
far as elasticity is concerned. We can only theorize. It
may be that heat enlarges the molecules. It may be that it
separates them. It may be that it reduces their cohesion.
All of these theories are more or less probable. The loss of
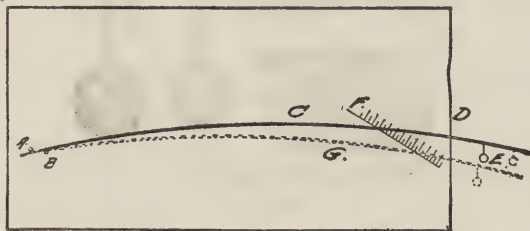
Fig. 189.

cohesion seems to be sustained by the fact that tempered
steel has greater tensile strength than soft steel. This is to
say, a strip of tempered steel will sustain, without break-
age, a greater weight than a strip of soft steel of the same
dimension. An argument against the theory is that tem-
pered steel will break from a lateral strain which will only
cause soft steel to bend. Reference to Fig. 190 will show
what is meant by these theories. It may be said of them all
that they are at best attempts to account for the fact that the
hairspring loses elastic force in heat, thus causing a watch

to lose time, and that this loss is greatly in excess of the loss occasioned by expansion of the balance.

That Berthoud was mistaken in that part of his statement which refers to the elongation of the hairspring producing an error of 19 seconds, may be readily proved by means of the device shown in Fig. 189. The length of spring used here is about 6 inches. Now the elongation of a spring 6 inches in length would be, for an increasing temperature of 60 degrees, about two thousandths of an inch.
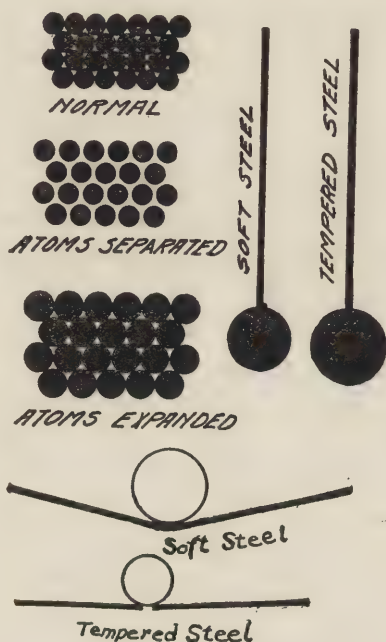
Fig. 190.

In a 16 or 18 size watch it requires a movement of the regulator pins of several times this amount to produce a change of 19 seconds. Add to this the fact that while the hairspring elongates it also increases in width and thickness practically in the same proportion and it will be readily seen

that the elongation of the hairspring can have no effect whatever on the variation of the watch.

To prove the above: First slide the weight along the spring to the extent of a hundredth of an inch and it will be found that the deflection caused thereby is so minute that it cannot be read by the use of a strong magnifying glass. Now heat the back of the plate, by blowing the flame of an alcohol lamp with a blow pipe against it and the spring will deflect very perceptibly, as shown by the dotted line, and upon cooling it will return. It may not return to its original position upon the first trial, owing to what is called "seasoning," but it will be found to do so upon subsequent tests. This proves the great loss of elastic force when a hairspring is heated.

A remarkable condition brought to light by experiments conducted by the author was that a watch regulated with a tempered spring showed considerable gain of rate when the temper of the spring was drawn.

It has been seen that heating a spring causes it to lose resilience, or elasticity. In view of this fact it would seem at first thought that drawing the temper, which of course is done by heat, would cause the watch to run slow, and it is an apparent anomaly that the opposite is the case. This can also be demonstrated by the device shown in Fig. 189: Take a piece of tempered mainspring; place it in position as shown at C. Note the position it occupies in relation to the index F. Place a small weight, E, on the projecting end, having previously marked the point where the weight is suspended. Note the amount of deflection that the weight causes in the spring. Having made a record of this, remove the spring and draw the temper by heating it red hot. Replace it and note the amount of deflection as compared with the same spring before the temper was drawn. It will be found that the deflection of the soft spring is less than when it was tempered. This accounts for why a watch

regulated with a tempered spring will run faster when the temper of the spring is drawn.

Another condition produced by drawing the temper of a hairspring is that its loss of resistance to flexure by heat is reduced, the effect of which is that a soft hairspring is more easily adjusted to temperature than a tempered one. To make the above more clear let us assume that a watch having a tempered spring shows no variation at temperatures 50 and 90 Fahr. When the temper is drawn it will show a variation in these two temperatures of several seconds. The
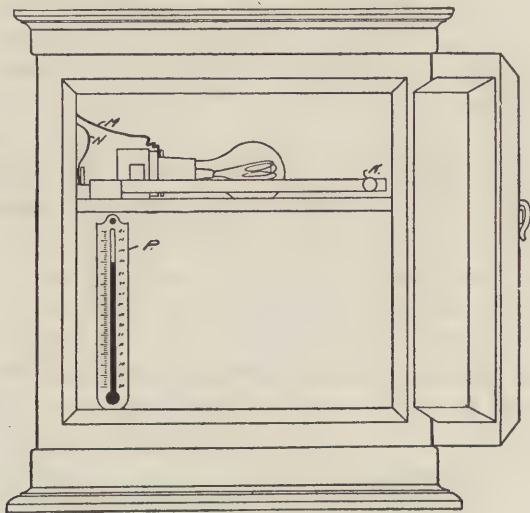
Fig. 191.

high temperature will show a faster rate than the low one. In other words, it will be over-compensated.

To adjust a watch to temperature some means must be provided for controlling the temperature to which the watch is submitted.

Every well equipped repair department should have means for conducting temperature tests. Fig. 191 shows a temperature cabinet suitable for this purpose. The inside

measurement may be about 12 inches square. This gives a
cubic foot of air, which is sufficient for proper circulation,
a less amount would render the temperature more difficult
to control. The door should be made to fit closely with the
door jamb set at an angle as shown. Packing may be used,
but if well seasoned wood is used in the construction this
will not be necessary. Some form of automatic controlling
device should be used with a high temperature cabinet in
order to maintain uniformity. An equipment of this sort
can be bought from a manufacturer of incubators and either
kerosene oil or gas used in connection with it. In fact, an
incubator can be used for a temperature cabinet, but would
be more unsightly than the one illustrated in Fig. 191.
Where electricity is available it can be made to serve the
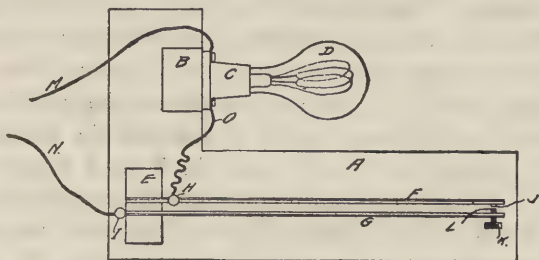
Fig. 192.

purpose much better than either kerosene or gas. A kero-
sene heater is always liable to smoke and fill the chamber
with soot. Gas is liable to go out from being shut off at its
source, and when turned on will fill the chamber with gas.
Electricity has none of these dangers and can be more
readily controlled than any other method.

Referring to Fig. 192: A is a wooden base; B, a
wooden block to which is secured a lamp socket, C, carrying
a bulb, D. E is a wooden block into which is let two bi-
metallic bars, F and G. These bars are each made of a
strip of brass ½ inch wide by .06 inch thick, and a strip of

steel ½ inch wide by .04 inch thick. The length is the same, about 12 inches. Solder the brass and steel bars together in pairs with soft solder. H and I are binding posts for the reception of insulated wires. K is an adjusting screw tipped with platinum, L. J is a piece of platinum attached to F. The object of having platinum faces is to prevent oxidization. M and N are wires leading from a rosette of electric wiring. O is a wire connecting the bar F with the lamp. The bars F and L are set with the brass sides facing each other. Having two compensating bars working against each other as shown doubles the amount of motion and makes a clean break at the gap, thus preventing sparking or arcing on the breaks.

This device acts on the same principle as a compensation balance. Heat expands the brass to a greater amount than the steel, thus curving the bars outward and breaking the electric circuit by separating the platinum faces. The adjusting screw K is used to set the making and breaking of contact at the proper point to regulate the temperature. When properly set it will maintain it to a fraction of a degree. A small resistance coil might be used instead of a lamp, but a 20-watt carbon filament lamp will answer the purpose and besides possess the advantage of showing by its light when the device is working properly. The consumption of current is scarcely appreciable inasmuch as the bulb will be lighted only a small fraction of the time consumed in the test.

Fig. 191 shows a cabinet with an electric device installed. Where it is used without a water jacket I consider it preferable to locate it as represented, the watches undergoing test being placed beneath the heater. The thermometer P should be suspended with its bulb near the lower side of the chamber in order to indicate the temperature while the watch is being tested. The entire cabinet should be lined with asbestos and a sheet of the same material placed be-

neath the lamp to prevent its direct rays striking the watch. This asbestos protection should have a number of large perforations in other parts.

STRUCTURE OF A COMPENSATION BALANCE. The compensation balance, the manufacture of which has been explained in a previous chapter consists of two metals, brass and steel. The arms are of steel; the rim, of steel and brass laminated—the inside steel, the outside brass. The proportions of the brass and steel in the rim are usually two-fifths steel and three-fifths brass. The brass has nearly twice the coefficient of expansion as the steel.
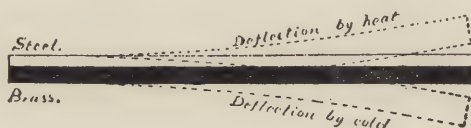
Fig. 193.

If we secure together throughout their length a strip of brass and a strip of steel and submit it to heat or cold, the brass expanding or contracting more than the steel will cause the bar to deflect as shown in Fig. 193. Should either metal be too greatly in excess of the other practically no deflection will take place. The metal having the greater mass will almost completely overcome the other, carrying it forward in a direct line just as though the bar was composed of a single metal. See Fig. 194.

Fig. 194.

It follows then that in order to secure the best action in the rim, the metals must bear a certain proportion to each other in dimension, density and structure. Proportions of

two-fifths steel and three-fifths brass are well adapted to this purpose.

In old style compensation balances the steel was generally tempered, which made it very active, and inasmuch as the brass was usually soft it was less active. The proportions then were about one-third steel and two-thirds brass. In modern balances the steel is left soft and the brass is hardened by rolling or hammering. The necessary proportions are then, as has been stated, about two-fifths steel and three-fifths brass.

The relative proportions between the width and thickness of the rim is a matter of prime importance. The thinner the rim in proportion to its width the more active it will be—the greater will be its deflection by changes in temperature; also the greater its deflection by centrifugal force, and the greater the danger of being put out of true from slight jars and the like. On the other hand, if the rim is too thick it will not be sufficiently active to secure close adjustment to temperature. It is evident that in order to produce a total given weight a thin rim must have a greater weight in screws than a thicker one, therefore the proportions of the rim call for careful consideration. The proportion of 36 percent of the width, for the thickness of the rim will secure sufficient rigidity to resist undue flexure from centrifugal force when the balance is at its highest speed, and yet allow close compensation.

The metals constituting the rim must be of uniform thickness throughout, otherwise the deflection of both sections of the rim will not be uniform, with a result that heat or cold will throw the balance out of poise. See Fig. 195. In this case the brass and steel are correctly proportioned at one side, which would of course produce the proper deflection, while at the other side the steel is greatly in excess of the brass for the greater portion of its length, with a result that the deflection of the rim at that side would be much less compared with the opposite side.

ACTION OF THE RIM.—Heat expands the metals of which a balance is composed. The arm elongates, throwing that part of the rim to which it is attached out from the center. The rim also elongates, but the brass on the outside expanding more than the steel on the inside causes it to curve inwardly this curvature increasing from the arm to the cut.

Fig. 196 will illustrate just how this curvature takes place. The full lines show the normal condition of the balance; the
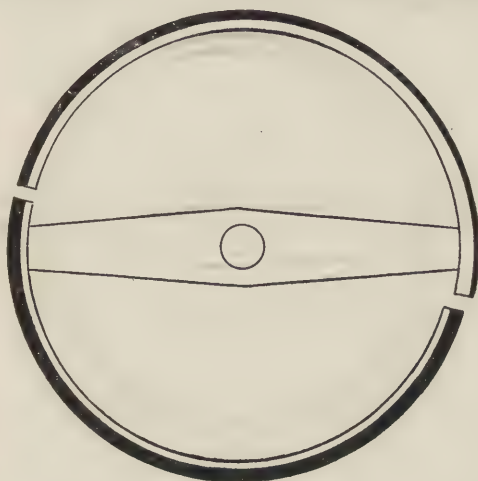
Fig. 195.

broken lines the effect of heat. It should be understood that in this drawing as in many of the preceding, the effects illustrated are somewhat exaggerated which is necessary in order to show the action clearly. It will be seen by reference to Fig. 196 that under the influence of heat the rim recedes from the center at A, approaching the center to a much greater extent at B, while at C it maintains the normal distance.

To fully understand the condition described above it is well to study this drawing 196, carefully. If all the metal

contained in the balance were concentrated at A, the result would be that it would recede from the center when heated and approach the center when cooled. While if it were concentrated at B, the opposite condition would be produced, which is to say, it would approach the center when heated and recede from it when cooled. Now if all the metal were concentrated at C, it would maintain exactly the same distance from the center, whether heated or cooled. This feature should be borne in mind in making alteration for ad-
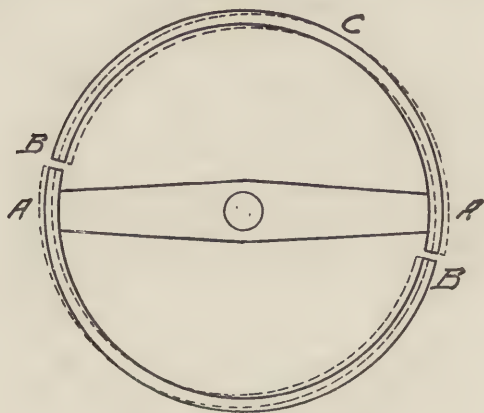
Fig. 196.

justment to temperature. I desire here to call attention to a peculiar condition produced by the deflection of a laminated balance rim: *A cut compensation balance can only be absolutely true in one temperature.* This can be readily understood by reference to Fig. 196, which shows the normal condition of the balance in full lines—its condition when heated, in broken lines.

Perfect adjustment for all temperatures cannot be secured by a compensation balance. For instance: If adjusted to temperatures of 40 and 90 degrees Fahr. it will gain at a temperature of 65, which is the mean of the two. The reason for this is that all parts of the rim do not move in

radial lines to and from the center, the parts directly at the ends of the arm only being thus affected.

Fig. 197 shows this in exaggerated form. The full lines show a balance rim distended under the influence of cold.
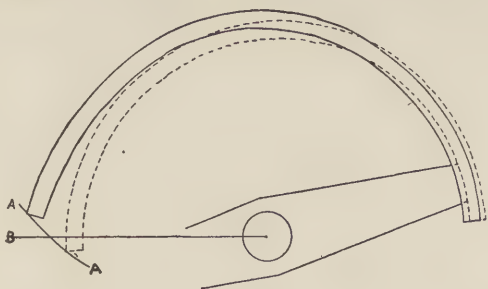
Fig. 197.
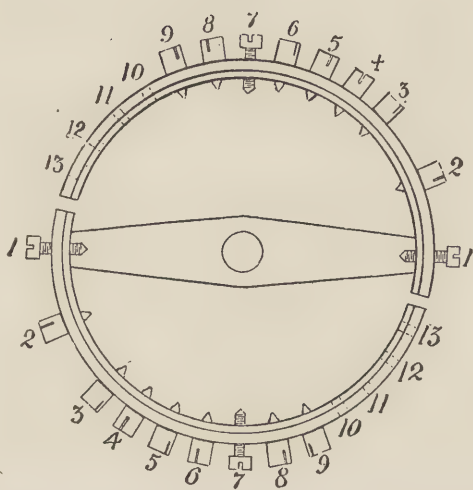
Fig. 198.

The broken lines show it contracted—curved—under the influence of heat. The curved line AA, represents the path described by the extreme end of the rim, which it will be seen is totally different from the radial line, B.

POSITION OF SCREWS—Compensation balances are provided
with several more holes in the rim than the screws used.
This is done to afford means for changing the position of
the screws in order to effect compensation.

Figs. 198 and 199 show two balances with screws dif-
ferently located, the screws and holes all being numbered
consecutively, beginning at the ends of the arm. These bal-
ances have each 26 screw holes—13 at each side. The num-
ber of screws varies dependent on the size, notch, etc., 2 or
4 may be meantime screws; we will consider a balance of 18
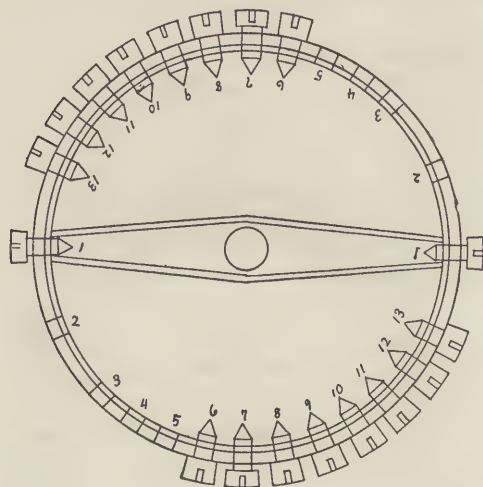
Fig. 199.

screws with 4 meantime screws. In Fig. 198, holes 1 to 9 in-
clusive hold screws, while 10 to 13 inclusive, are vacant.
This condition is called "all screws back." In Fig. 199,
which has the same number of holes, 2 to 5 are vacant,
while 1, and 6 to 13 inclusive, hold screws. This is called
"All screws forward." Holes 1 and 7 contain meantime
screws which are never changed to other holes.

The student, having equipped himself with a temperature
cabinet should make trials of several watches for the sake of

practice in timing, before attempting adjustment. For this purpose he should rule a few rate papers. A convenient size for these is 8½ by 3½ inches.

Date	Time	*Temp 90 and 40* Dif	Var	Error
Jan				
6	9 30	0 0		
7	9 30	−14	−14	
8	9 30	−14	0 0	Und. 14
		0 0		
2		0 0	0 0	
		+14	+14	Und. 14
		0 0		
3		−7	−7	
		0 0	+7	Und. 14
		0 0		
4		−3	−3	
		+8	+11	Und 14
		0 0		
5		+3	+3	
		+20	+17	Und. 14
		+.5		
6		+4	+3.5	
		+21.5	+17.5	Und. 14
		−1.5		
7		+1.5	+3	
		+18.5	+17	Und 14
8		+1		
		0 0	−1	
		+13	+13	Und 14

Fig. 200.

The ruling shown in Fig. 200 will be found convenient for the purpose. The first column to the left is for the date; the next for the time when comparison was made; the next for the difference in time between the watch and clock or

other standard of comparison; the next for the gain or loss as compared with the previous comparison; the column at the right for the temperature error. The temperature at which the watch was run, or other matter, may be also inserted in this column if desired.

RULES TO BE OBSERVED IN TRIALS—See that the watch is in perfect order and freshly oiled. If the oil is thick or viscid the cold temperature will make it more glutinous and retard the motion of the balance.

Be sure that the balance has a sufficient amount of end and side shake. The plate and cock being composed of brass or nickel, contract more in the cold than the balance staff, therefore in case of a close endshake it is likely to bind, retarding the motion, and sometimes even stopping the watch.

Always make comparisons of the watch with the clock or other time piece by which it is timed when the seconds hand of a *watch* is at 60, regardless of where the seconds hand of the *clock* may be. This is for two reasons: First, should there be any error in the spacing, or in the centering of the dial, it will thus be eliminated so far as any difference when the comparison is taken. Second: It lessens the liability of mistakes in time as will be apparent later on.

In timing, carry the tick of the clock or chronometer mentally, keeping the gaze steadily fixed on the watch. A marine chronometer is excellent to use as a timer for the reason that it beats half seconds, but a little practice will enable any one to estimate half seconds very closely from a clock beating seconds. Practice counting first: beginning when the second hand of the clock is at 60, thus: half, one; half, two; half, three; half, four; half, five; and so on. In timing watches begin to count when the hand of the watch is approaching 60, and about 10 to 15 seconds from it. Let us assume that the hand of the watch being timed is approaching the 60 and the hand of the clock approaching the 30 when the count is begun. We begin: five; half, six;

half, seven; half, eight; half, nine; half, thirty; half, one; half, two; half. At this moment the second hand of the watch reaches 60. It follows then that the watch is either 32½ seconds slow, or the difference between that and sixty, which is 27½ fast. A glance at the minute hands will determine whether it is fast or slow, and in case it is a fraction of a minute or one or more minutes will be readily seen.

Run the watch both in high and low temperatures in a horizontal position with the dial up. There are two reasons for this: First, it is easily compared without disturbing its position, second and more important still, it avoids the introduction of any position errors that might exist in the watch.

The watch may be run in its own case, or it may be run in any close shutting receptacle which, while not necessarily air tight, should be at least dust tight. Run the watch 24 hours in each trial, timing it as nearly at the same hour as possible. A few minutes earlier or later will make no difference; but there should not be a difference to the extent of an hour. In case the timing should be forgotten at the proper time, it is better to give the watch another trial.

Wind and set; then run the watch in the high temperature; after timing, wind it, but do not set it and run in low temperature. The difference in time will show the variation.

After removing from the cold cabinet do not open the receptacle or case for at least an hour. This gives it time to attain the temperature of the air in the room, and is a preventive of rust. If the case were to be opened immediately upon being removed from the cold cabinet the watch would "sweat" as it is called; that is, the moisture from the air would condense upon the steel parts and possibly produce rust.

FIGURING RATES AND MAKING ALTERATIONS—In making out rates, signs and abbreviations are commonly used in

order to economize space and time. The plus sign is used to indicate when the watch is fast of the clock, the minus sign to indicate when it is slow. The plus sign may also be used to indicate what is termed over-compensation, the minus sign to indicate under-compensation. A watch with a balance made of a single metal and having a steel hairspring will, if regulated in mean temperature, gain in the cold and lose in the heat. This we call under-compensation. When a watch gains in the heat and loses in the cold we say it is over compensation.

An important rule to be observed in figuring rates is: When the signs indicating the cold and the heat variations are alike, subtract the lesser from the greater. The re-
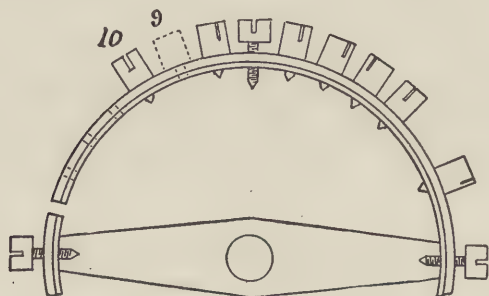
Fig. 201.

mainder is the error. When the signs are opposite add the two together. The sum will be the error.

A watch running in both temperatures on fast rates, but faster in the cold than in the heat, is under-compensated, because if that watch, having gained, say 15 seconds in the cold and 5 seconds in the heat, had been regulated so as to gain five seconds in the cold it would of course have lost 5 seconds in the heat; a watch therefore gaining more in the cold than in the heat is under-compensated.

Gaining less in the cold than in the heat is over-compensation.

Losing more in the heat than in the cold is under-compensation.

Losing more in the cold than in the heat is over-compensation.

MOVING THE SCREWS—When a watch is under-compensated, one or more of the screws should be moved forward as indicated in Fig. 201, where the dotted lines under 9 show that the screw has been moved forward to 10. When the watch is over-compensated, one or more screws should be moved back as shown in Fig. 202. Moving a screw forward
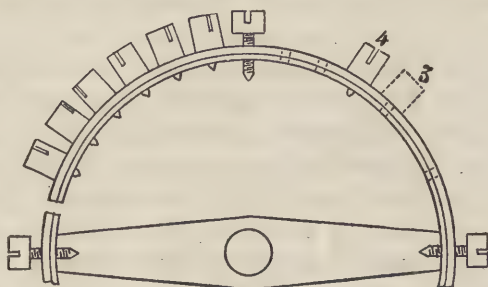
Fig. 202.

or back on a rim a given distance does not always produce the same result. There are many causes for variation, to one of which I desire to call particular attention which is the varying curvature of the rim as illustrated in Fig. 196. It will be seen that a limited movement forward or back, at C, would produce little or no change in the compensation as compared with the same amount of movement at B, for the reason that the part of the rim at C changes its radial distance from the center of the balance very slightly, while at B, the radial distance undergoes considerable change.

Fig. 200 shows eight suppositious trials of watches in which the rates widely differ, although the errors are alike. a careful study of this table will be material aid in making oneself familiar with the method used. The trials are each

of twenty-four hours duration, the first being in high temperature—90 degrees, the second in low temperature—40 degrees.

In the first trials the watch was set exactly with the clock and placed in the heat. When taken out it was 14 seconds slow. It was wound and placed in the cold without resetting and when taken out it was still 14 seconds slow, not having varied during the trial. Referring to column 4, we have carried out the heat trial—minus 14—for the cold trial 00. The loss being in the heat we have marked it "Und 14." In the second trial it did not vary in the heat, but gained 14 seconds in the cold, which we find marked "plus 14" in the 4th column. The watch was also "und 14." In the third trial the watch lost 7 seconds in heat and when taken from the cold was found to be correct, it having gained the 7 seconds which it had lost previously, consequently the 4th column is carried out minus 7 and plus 7; the signs being opposite were added, making 14, and as the loss was in the high temperature it is marked in 5th column "und 14." In the fourth trial the watch lost 3 seconds in the heat and was found to be 8 seconds fast when taken from the cold, it having gained not only the 8 seconds but also the 3 seconds it had lost previously, making a gain of 11 seconds in the heat, as marked in the 4th column; adding to this the 3 it lost in the heat makes 14; it is therefore "und 14" seconds. In the fifth trial the watch gained 3 seconds in the heat and was fast 20 seconds when taken from the cold, having gained 17 seconds. These signs being similar the less is subtracted from the greater leaving the watch also "und 14." In the sixth trial the watch was fast .5 and when taken from the heat was fast 4 seconds, having gained 3.5. When taken from the cold it was 21.5; a gain of 17.5, the difference being 14. It was therefore "und 14." In the seventh trial the watch was slow 1.5 when placed in the heat and fast 1.5 when taken out, having gained 3 seconds. It was fast 18.5 when taken from the cold, having gained 17 sec-

onds. 3 from 17 leaves 14—"und 14." In the eighth trial the watch was fast 1 second; when taken from the heat it was exactly with the clock; when taken from the cold was fast 13—"und 14."

The following trials and alterations were conducted on an actual watch, the balance of which was screwed up as represented in Fig. 198; the trials were of 24 hours duration.

In the first trial it showed an error of 9 seconds slow, in a temperature of 90 degrees Fahr. and fast 28 seconds in a temperature of 40; it was therefore 37 seconds under com-
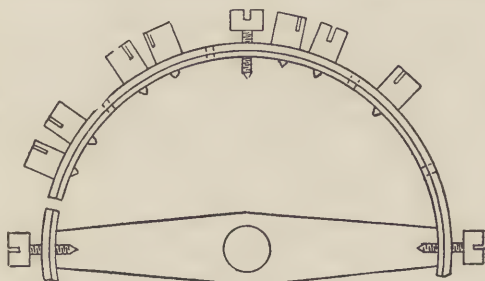
Fig. 203.

pensated. Screws were moved as follows: 9 to 13, 8 to 12, 6 to 10, 5 to 9, which left screws in holes 1, 2, 3, 4, 9, 10, 12, 13. This reduced the error to 12 seconds under compensated. An alteration was now made by moving 4 to 6, 3 to 5 and 2 to 4. The trial following showed 2 seconds over compensated. Screw 4 was then moved back to 3 and the trial following showed a uniform rate in both temperatures. This left the screws as shown in Fig. 203.

It is seldom necessary to remove the balance for the purpose of making alterations in position of screws. By using a shell screw driver they may generally be removed and replaced without risk. In exceptional cases, however, the screws may be found to fit so tight that it will be safer to take out the balance.

The taking out of balance screws and inserting them in other holes in the balance rim almost invariably throws the balance more or less out of true, and out of poise, but if the watch is run in a horizontal position it will merely change its rate without interfering with its compensation.

After the adjustment has been secured the balance should be trued and poised and the watch timed, then tried in temperature again for the purpose of remedying any error in case it should be apparent.

ISOCHRONAL ADJUSTMENT—The term Isochronal is of Greek derivation and means equality of time. As used in connection with time pieces it is applied to a condition of the hairspring that will cause the balance to occupy equal periods of time in describing its arcs, of whatever amplitude they may be. In other words, causing a watch to run at the same rate when first wound that it does when it has run 24 hours or more.

The first announcement made of this principle was by Dr. Hooke, in 1635—"Ut tensio, sic vis"—as is the tension so is the force. This is unquestionable, but to make a spring and balance isochronal, the force of the spring must vary in exactly the same proportion as the extent of the vibration of the balance. The vibrations of a balance controlled by a spiral spring do not necessarily conform to these conditions.

We are told that maintaining the center of gravity of a hairspring at the center of the balance will secure isochronal vibrations and as a consequence a practice became prevalent of making the spring to consist of complete coils. When a spring of an even number of coils, all of which are complete and is trued on a balance and at rest, its center of gravity coincides with the center of the balance.

Fig. 204 shows a single coil of hairspring illustrating how the center of gravity may be found. The coil is spaced into 16 equal lengths and the center of each marked with a small

circle, these being numbered. These circles are the centers of gravity of the pieces.

A line, AA, is drawn tangent to the outside coil of the spring and a line, BB, at right angles to AA, also tangent to the outer coil. Two lines are drawn from each center of the divisions of the spring, one perpendicular to line AA, the other to line BB. Adding together, the several lengths of the lines running to AA, and dividing the sum by the
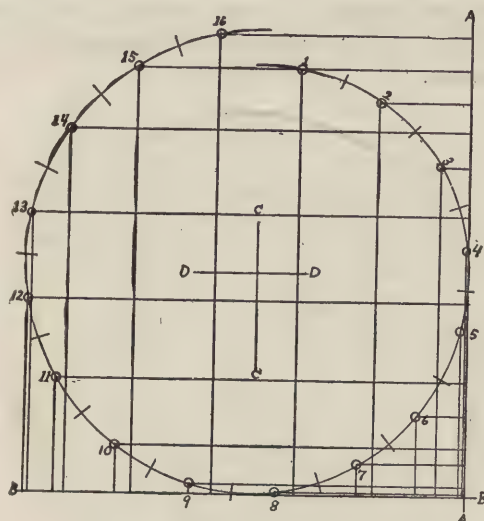
Fig. 204.

number of pieces—16—gives a distance for drawing the line CC, parallel to AA. This being the mean distance of the centers of gravity of the several pieces, from the line AA, the center of gravity must be located somewhere in the line CC. Proceed in the same manner with the lines running to BB and draw the line DD. Where the lines CC and DD intersect is the center of gravity of the coil. This point coincides with the center of the balance. Every coil will conform to the same condition as a consequence. The center of gravity of the entire spring will therefore be at the center of

the balance. This condition, however, can only exist when the spring is at rest. The moment the balance is set in motion, the outer coil ceases to be complete. As the spring is wound, the coils are added to by a fraction so to speak, and as it unwinds they are subtracted from. As the motion of the balance increases, these fractions increase until, when the motion reaches a turn the difference amounts to one entire coil. This is to say, assuming that the spring has 14 coils when the balance is at rest, when it is in motion to the extent of a turn the coils will be alternately 14½ wound, 13½ unwound.
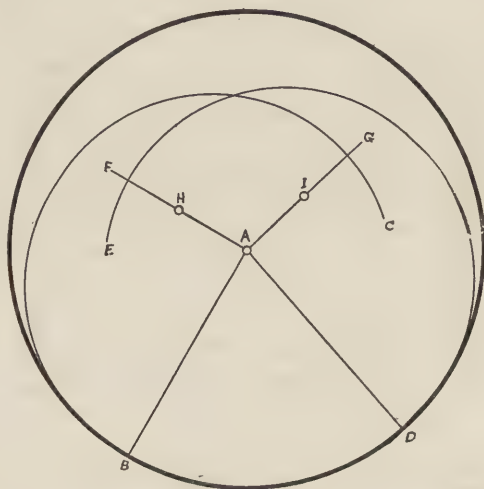
Fig. 205.

The celebrated engineer, M. Phillips has mathematically solved the problem of maintaining the center of gravity of a hairspring in action, at the center of the balance.

Fig. 205 shows his method applied to a cylindrical spring. In this Figure A, is the center of the spring, BC and DE are the terminal curves. Draw a radial line from B and D to the center of the spring and lines F and G from the

center of the spring and at right angles to BA and DA. Divide the square of the radius by the length of a terminal curve and with the quotient set off points H and I from the center of the spring. Points H and I must be the centers of gravity of the terminal curves, which being the case, the common center of gravity of the spring including the terminal curves will be at the center Λ. What is meant by this illustration is that the condition must correspond with these requirements. To produce the same condition in a spiral
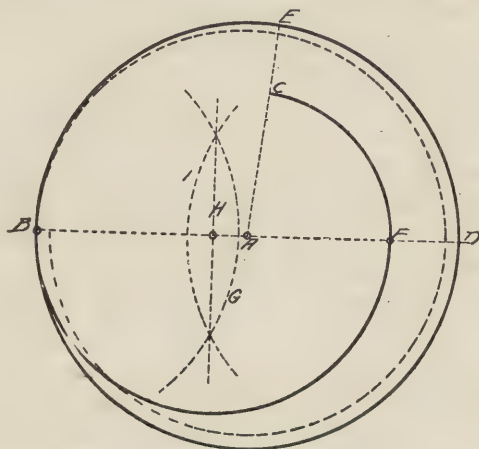
Fig. 206.

spring, an inner terminal curve as well as an over-coil is required.

Upper and lower terminal curves are invariably used in marine chronometers, but an inner terminal curve is seldom used in a watch.

It must not be understood that the terminal curves shown are the only forms which can be used, but the conditions described are necessary to produce theoretical isochronism.

For the method illustrated by Fig. 206 I am indebted to "Practical Course in Adjusting," by Theo. Gribi.

The figure illustrates a method for the formation of a terminal curve which can be used in both outer and inner curves, that will be suitable for conditions found in a large majority of watches.

A is the center of the balance. The broken line is the outer coil of the spring from B where the over-coil commences. The full circle is produced with the radius AB. Draw line BD, through the center of the spring. With the dividers set at 67 per cent of the radius, draw an arc of a
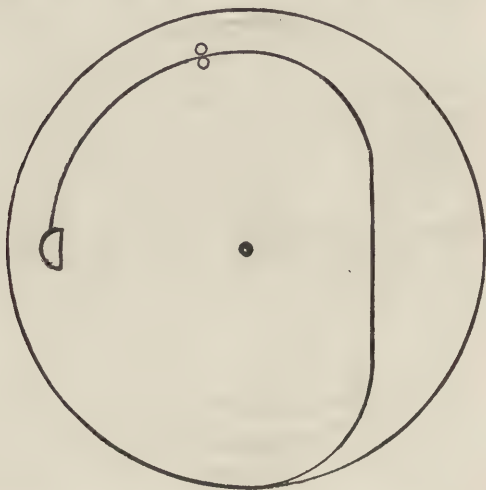
Fig. 207.

circle, CF, the radial line AE, 83 degrees from AD. Draw arc I from F and arc G from D. Draw a line H through the intersections as shown. The intersection of H with radius AB gives the center from which is drawn arc BF. Curve BFC is the over-coil

A little pamphlet by Professors James and Golay of the Geneva Horological School, Switzerland, gives eight groups consisting each of 25 forms for over-coils. They are actual size, specially prepared for the students of that institution

and are of a great variety of shapes, covering practically all sizes of watches. It is deemed unnecessary to reproduce them here.

The curves for the over-coil may be divided into two general classes: The gradually changing curves, and the flattened curves, of which Fig. 205 and 206 are examples of the former; 207 of the latter.

Fig. 207 shows the entire length of a flattened over-coil to the stud. The location of the regulator pins are also shown. Variations may be made in the shape of over-coils where theoretical isochronism is not a requirement.

It is impossible to maintain the center of gravity of a spiral spring with a single terminal curve, at the center of the balance. When two terminal curves conforming with the Philips' formula are used it can be accomplished, but even in this case isochronism is by no means certain. It answers the purpose sufficiently well for a marine chronometer, because the conditions are favorable. The instrument is maintained in a perpendicular position, thus securing equality of friction. The power is equalized by the fuzee. The vibrations are 7,200 an hour, hence the balance moves at less than half the speed of a watch balance, thus causing less dilation by centrifugal force, and the instrument is not subjected to such sudden agitation or shocks as a watch. The effect of these favorable conditions will be better appreciated by comparing the rates of a marine chronometer in the vertical and horizontal positions.

A chronometer in the test suggested still has the advantage over a watch in these particulars: Uniformity of power, and less deflection of the balance.

There are so many antagonistic conditions, both inherent and extraneous to the hairspring, ·which affect isochronal vibration, that although the hairspring may be theoretically correct, yet the vibrations of the balance may be very far from isochronous. In fact, it is not necessary, and generally

speaking, not advisable that the accepted theories of isochronal conditions for the hairspring be too closely adhered to.

POSITION ADJUSTMENTS—For adjustment to positions no fixed rules can be laid down that can be depended upon to produce predetermined or invariable results in all cases.

The means of correction for errors in position are to a great extent a matter of judgment and sometimes of experiment. A means that will correct an error in one watch may, when applied to another watch having precisely the same error, produce the opposite result.

There is an individuality about watches, probably due in a great measure to differences of design, construction, slight differences in proportions of parts, density, or structure of material, as well as other causes. Many of these are of such trifling character as to escape observation.

As has been explained elsewhere in this work, there is a distance from the center of the balance called the radius of gyration. If this distance is used to describe a circle and the entire weight of the balance were concentrated on that line, the time of vibration of the balance would be unchanged. This circle is called the circumference of gyration. When a cut balance is in motion the rim is thrown outward by centrifugal force. This moves the circumference of gyration outward, causing the watch to lose time. The long arcs cause a greater loss than the shorter ones.

The varying friction of the balance pivots in their jewels is another cause of disturbance. When a pivot is running on its end, the retardation by friction is necessarily less than in a pivot running on its side.

Friction in the abstract is independent of extent of surface in contact and of velocity. This being the case, it would seem that a pivot with a perfectly flat end will meet with no more resistance when running on a perfectly flat endstone than when running on its side in a hole jewel, yet

the fact is that the motion of a balance when it is allowed
to acquire its maximum extent in a horizontal position is
invariably reduced when the watch is placed in a vertical
one.

This may be due to a condition shown in Fig. 208 in
which A is the center of a pivot having its bearing in a
jewel of which B is the center. CC is a vertical line. The
pivot is revolving as indicated by an arrow. The unusual
difference between the size of the pivot and its jewel is for
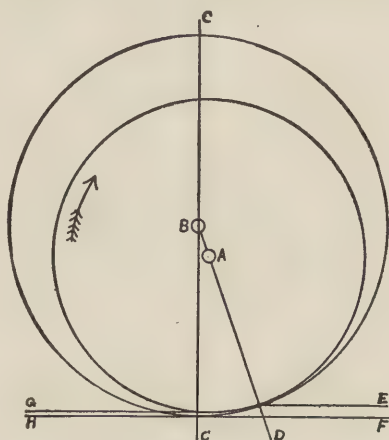
Fig. 208.

the purpose of showing clearly the action. As the pivot re-
volves it has a tendency to move forward and begins to
ascend an incline. Assuming that it has ascended to the
point shown by line D, its tendency to ascend further is
overcome by the resistance offered by the constantly in-
creasing pitch of the incline. The adhesions of the surfaces
caused by the weight of the balance has brought the point
of contact to the intersection of line D with the jewel, or a
height equaling the distance between lines E and F. The at-
traction of gravity has been overcome to the extent of lift-
ing the balance to a height represented by lines G and H.

At this point friction overcomes adhesions and the pivot rotates against the jewel at one point.

ADHESION OF OIL—The use of a lubricant is essential as a preventive of excess abrasion. Oil causes adhesion which has a retarding effect. Adhesion increases with increase of surface. Hence, while a long bearing does not increase friction, it does increase the resistance of adhesion, and this resistance increases with the thickening of the oil.

The main ingredients of watch oil are olein and stearine. The stearine increases the density of the mixture, giving it more body and rendering it less liable to evaporate. When oil contains an excess of stearine, the latter precipitates, forming a white sediment. Oil will, however, hold in solution a certain amount. When in a state of agitation it is capable of holding in solution a greater proportion of stearine than when the oil is at rest. This property of oil accounts for the fact that if a watch carrying a close rate is allowed to run down—even for 24 hours—its rate will change. The longer the oil has been in the balance jewels the greater the change of rate. While the oil is kept in a state of agitation by the rotation of the pivots in their jewels, its ingredients are kept thoroughly mixed, but when the agitation ceases the stearine immediately begins to coagulate, and once condensed, no amount of agitation will redissolve it. The minute globules offer increased resistance by adhesion, and the watch will lose or gain on its previous rate conformably with its isochronal condition.

Just here it seems eminently proper to give some simple and efficient directions for testing and caring for watch oil.

The main difficulties to be apprehended are viscidity and acidity. In addition to defense against these enemies it should be seen that the oil is of the proper consistency. Three easily conducted tests will secure comparative immunity from these evils.

First: Place a small drop of the oil to be tested upon a watch glass. Submit it to a temperature of freezing, or as near that point as you can secure. After it has stood 30 minutes remove it quickly and insert the point of a fine broach or pointed wire into the drop, lifting the point slowly. If the oil is stringy it has too much viscosity and would thicken about the jewels and pivots in a short time. In conducting this test it should be done immediately on removing the oil from the cold; before the glass has time to change its temperature.

Second: Put a drop on a glass, as before, and submit it to a temperature of 112° F. If it spreads to any great extent, it indicates too little viscosity and it would soon evaporate from the pivots and jewels.

Third: Take a piece of pure sheet copper—an old dial copper will answer—make a small indentation in it. See that the copper is perfectly cleansed—absolutely free from acid and alkali. Put a good sized drop in the indentation and place the whole in a dust tight box provided with a glass top. Give the box a southern exposure where the sun can shine upon it for 30 days. Should the oil turn dark or red, it indicates the presence of foreign matter; if it shows even a faint tinge of green, it indicates the presence of acid. In either case it would be sure to rust and cut the pivots in the course of time. Each individual bottle should be thus tested. The bench oil cup should be kept scrupulously clean; the oil changed once a week or more often. The bottle of oil, after being tested, should be kept in a cool, dark place. In applying it to a watch use a finely tapered gold or steel wire flattened at the point—never use brass. A tube oiler is a dangerous instrument. The oil it contains is sure, sooner or later, to become foul and develop acid. When this takes place it is impossible to completely remove the taint, therefore any fresh oil will quickly become impure.

RESISTANCE OF AIR—This is a factor that must be given due consideration. The greater the speed of the balance the greater the resistance. Consequently, the wide arcs are retarded more than the shorter ones.

INERTIA—Inertia, mechanically speaking, is the tendency of a body to remain in the condition in which it happens to be; if at rest to remain so; if in motion, to remain at the rate of motion it then possesses. Overcoming inertia may mean starting a body up from a dead rest, or, if in motion, accelerating or retarding that motion. The term "moment of inertia" means a measure of a tendency to produce motion or to resist a change of motion. The inertia of a hairspring is said to accelerate the short arcs.

SAG OF THE HAIRSPRING AND BALANCE—By sag of the spring is meant its distortion by the attraction of gravity.

If a spring is secured to the collet, the outer end being free, and is held in a vertical position a sag will take place in the coils. This sag will be least near the collet, gradually
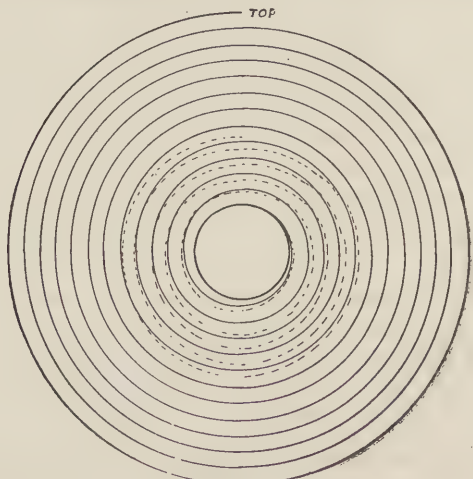
Fig. 209.

increasing toward the outer coil. Fig. 209 illustrates the condition, in which the full lines represent the spring in its true shape; the broken lines, a portion showing the gradually increasing displacement.

If a spring is secured at the stud, it being at the top as in Fig. 210, its sag will be greatest at the center. With the collet and stud both in place, the greatest amount of sag will be about midway between the inside and outside coils. The tendency of this sag is to disturb the poise of the hairspring. The two sections of the rim of a cut balance also
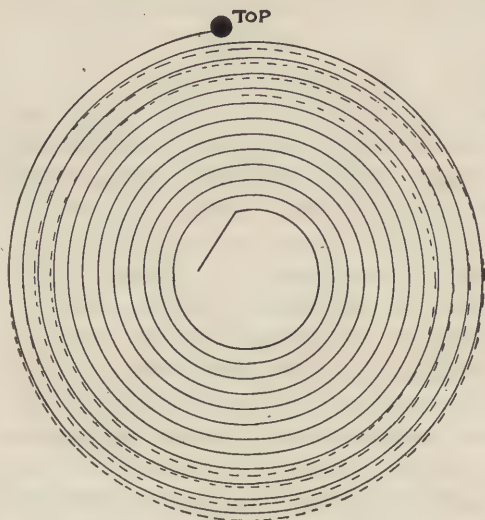
Fig. 210.

have a sag when the watch is in a vertical position, but the amount is so slight that it may be neglected.

IMPULSE AND LOCK OF THE ESCAPEMENT.—If we take a watch that is running on an even rate, and lifting off the balance cock without detaching the balance or disturbing anything else and turn the hairspring collet on the staff, the watch will be, of course, out of beat. It will be found

also that the rate has been thereby changed. This change is solely due to a change of the delivery of impulse with regard to the point of rest, for that is the only change we have made. When the watch was in beat the impulses were delivered at equal distances from the point of rest of the balance and spring, the point of rest being on a line drawn from the center of the balance to the center of the pallet arbor. When we move the collet, we have moved the point of impulse, which no longer takes place at the point of rest.

It is important that the student should understand this vital factor. To verify the statement made above, I shall ask the reader to try a simple experiment by the use of two pendulums of equal time of vibration.

Procure two articles of the same shape and of equal weight; two window sash weights will answer. Suspend them at a distance from each other of about 6 inches. Let the length of cords be, not less than 39 inches. This length will cause them to vibrate seconds, but it will be better still to have the cords longer; the longer the better. The cords must be of exactly equal length. This will give you two pendulums of equal time. Provide a mark of some sort to correspond with the pendulums when at the point of rest. A box with a small strip of wood set upright, placed directly under the pendulums will answer the purpose. Set the pendulums vibrating in unison and in arcs of the same extent. Taking position to bring the swinging pendulums in line, deliver an impulse to the front one after it has reached the limit of its swing to the right and is about half way to the point of rest. The result will be that the pendulum to which you have given an impulse will gain on the other. In other words the front pendulum will reach the point of rest before the other. Again set the pendulums vibrating in unison. Wait until it has passed the point of rest and is receding from it to the left; give it an impulse in the direction it is vibrating. The result will be that the pendulum to

which you have given an impulse will lose from the other and will reach the point of rest after it.

Observe that in both cases impulses have been delivered in the direction the pendulum was swinging; also that in both cases, the arc of oscillation has been increased, yet in one case the time consumed in completing the excursion to the left and returning to the point of rest has been accelerated and in the other, retarded.

Fig. 211 explains this apparent incongruity.

In this figure a second pendulum is shown in 9 positions, marked B to J inclusive, the point of suspension being A.
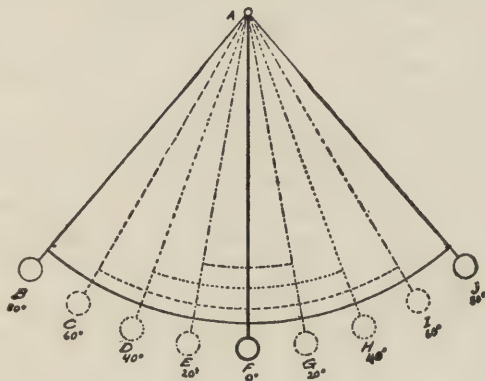
Fig. 211.

The positions in which the pendulums are shown are 10 degrees apart; F is the point of rest. If we set the pendulum swinging from E to G it will be swinging through an arc of 20 degrees, and being a second pendulum will do so in one second. If we set it swinging from D to H, which is 40 degrees, it will occupy also one second. From D to H being twice the distance of E to G the pendulum must travel at twice the speed. From C to I being three times the distance it must travel at three times the speed and from B to J at four times the speed. A pendulum will occupy half the

time in swinging from either extreme of its oscillation to the point of rest, or from the point of rest to either extreme; therefore whatever extreme it may be swinging from, it will, if undisturbed, reach the point of rest—F—in half a second. If, however, its rate of motion is changed during its passage, the time of its passage will also be changed as has been demonstrated in our former experiment.

Let us assume that a pendulum is swinging between D and H, and that while it is approaching F—swinging to the left—we deliver an impulse at G that will carry it to C, we will thus have caused it to pass from H to F in less time than half a second. The reason for this is that the pendulum has traversed from H to G at a speed belonging to an arc of 40 degrees, and from G to F at the higher speed belonging to an arc of 60 degrees.

Assuming that a pendulum is swinging, as before, between D and H, and that while it is approaching D swinging to the left, we deliver an impulse at E that will carry it to C. We will thus have caused it to consume more time than half a second in passing from F to C, notwithstanding the fact that we have accelerated its motion, for the reason that in order to accomplish the arc F C in half a second, the speed from F to E must be that of an arc of 60 degrees; but as the pendulum before being accelerated traveled a distance between F and E at a speed of an arc of only 40 degrees, thus making a less speed for the total arc FC, or in other words, consuming more than a half second of time.

Let us again experiment with the two pendulums swinging in unison. Retard the motion of the front one after it has reached the limit of its swing to the right and is about half way to the point of rest. The result will be that the pendulum which you have retarded will lose from the other. In other words, the front pendulum will reach the point of rest after the other. Again set the pendulum vibrating in unison. Wait until it has passed the point of rest and is

receding from it to the left, retard its motion and the result will be that the pendulum which you have retarded will gain on the other and will reach the point of rest before it.

Observe that in both cases the motion of the pendulum has been retarded, also that in both cases the arc of oscillation has been diminished, yet in one case the time consumed in negotiating its excursion to the left and returning to the point of rest has been increased and the other diminished.

Again referring to Figure 211. Assume that a pendulum is swinging from B to J and that while it is approaching F, swinging to the left, we retard its motion at H, causing it to swing only to D; it follows then that it will have covered the distance from J to F in more than half a second, the reason being obvious.

Assuming that a pendulum is swinging as before, from B to J and that while it is approaching B, swinging to the left, we retard its motion at D, causing it to swing only to C; it follows then that it will cover the distance from F to C in less than half a second, as it travels the distance FD at the speed of an arc of 80 degrees and the distance from B to C at the speed of an arc of 60 degrees.

From the above experiments we are able to make the following deductions:

Accelerating the motion of the balance before the point of rest, causes a gain in time.

Accelerating the motion beyond the point of rest causes a loss in time.

Retarding the motion before the point of rest causes a loss in time.

Retarding the motion after the point of rest causes a gain in time.

There are a number of causes which would give these varying effects in a balance:

The pressure of the guard pin on the roller.

A sudden jar as the watch is carried in the pocket.

Insufficient lock on the escapement.

Unequal impulse, or the watch being out of beat, and other items too numerous to reiterate, as the subject has been covered under the headings of escapement, train and balance, in the previous chapters on those subjects.

Other causes of nonuniform rates in watches can be determined only by a very careful and thorough examination and in order to prove conclusively where the trouble may be, it is advisable to make note at the time of the examination just what these troubles are and consider each carefully and what its effect might be on the time, before making any alterations. Then make an alteration to correct one of these troubles and again time the watch. Thus through a process of elimination you may determine the cause and effect for future reference.

CHAPTER XV.

WORKMANSHIP.—Always do good work and charge for it. Poor work does not pay. A patron may forget the price charged. Even if he at first considers it excessive he is likely to become reconciled provided his watch gives satisfaction; but let it be unsatisfactory, no matter how little he paid he will feel that it was too much.

If, for want of proper equipment, or lack of skill, you cannot do a piece of repair work properly, send it out to be done. It is no disgrace to admit a lack of equipment, or of ability; but bad work is reprehensible. That there is too much bad work done is evidenced by the following:

At the suggestion of the editor of The American Jeweler the author of this work kept a record of over a thousand watches received from retailers by the watch factories for repairs, with the idea of determining the most common delinquencies of watchmakers of the present day. This "hospital" record was made up—not of selected watches—but of watches in the order in which they were received. The general condition of these watches was carefully noted with a view of determining how much of the work was due to ill usage given them by the owners, and how much to bad handling by the retail jeweler or his watchmaker. The result is given below:

	Per cent.
Broken jewels	43
Balance pivots injured	18
Balance pivots broken	3
Rusty hairsprings	4
Mutilated hairsprings	1
Mainsprings broken or unsuited to the watch	6
Broken dials	4
Imperfectly fitted and broken jewel pins	2
Pallet stones injured	3

Balances injured beyond correction............ 1
Barrels injured............................... 1
Miscellaneous 14

It is seen that by far the greatest damage was due to broken jewels. Broken jewels are generally the result of misusage on the part of the watch owner. The next greatest was from injured and broken staffs.

Much of the injury to balance pivots may be laid to the charge of the watch repairer.

About half the repairs under the head of Miscellaneous became necessary from improper handling by negligent or poor workmen.

Now it is far from our intention to insinuate that the majority of watch repairers are poor workmen. The condition of watches received does not represent the average ability of watchmakers throughout the country. We only get the worst. There are many skilled workmen amongst the watch repairers of America, both foreign and native. These men as a rule do not send watches to factories for repairs. They purchase the material from the factories, fitting and adjusting it to the watches themselves. There is no justification for botch work on an American watch. Any part may be procured from the factory where the watch is made. The workman is not obliged to make anything.

A poor or careless workman is tolerated by the public because the watch owner has no means of knowing whether the repairs have been properly done or not. He is at the mercy of the watchmaker. This is an encouragement for the novice to take up the practice of our honorable art without having received proper instruction.

In England, Germany, France, Switzerland, Sweden and many other countries an apprentice is required to pass a rigid examination before being entitled to employment as a journeyman. In the United States anyone may pose as a repairer of watches, even though he may not have had an hour's instruction. There is absolutely no excuse for this.

We have horological schools where a theoretical and practical knowledge of the business may be acquired. The author has visited almost all of these institutions and finds that the general complaint of the faculty is that, with a few exceptions, the students are unwilling to devote sufficient time to learn the business properly. This applies particularly to acquiring that skill of hand and eye which makes a competent workman. Conditions are thus brought about that work hardship on American watch factories, which are often blamed for something caused by misusage after their product has left their hands.

Many watches are returned, that although obviously botched, yet are claimed to have been received in the condition in which they are sent in. Some of these are butchered almost beyond belief.

CHARACTERISTIC MISTAKES OF AMERICAN WATCHMAKERS TODAY.—Whenever a question is admissible as to whether the fault found in a watch returned to the factory is due to factory neglect, accident in transportation, or bad handling by the jeweler, it is usual to give the jeweler the benefit of the doubt; but when the watch bears the ear-marks of bad workmanship the job is charged for. When a watch is returned with a wretchedly filed brass pin in place of the roller jewel and the man returning it claims to have sent it in exactly the condition in which it was received, that point is reached where human endurance ceases to be a virtue.

In justice to American watch manufacturers, and in order to call attention to bad workmanship as found in watches returned to these manufacturers, attention is called to a few instances that will illustrate the faults and bad workmanship too often found.

Some watch repairers have contracted bad habits in their work without realizing it—habits acquired while learning, either from their instructors or from other workmen that they may have copied, under a false impression that what-

ever they did was right. A man may have devoted years to the business and yet not be a careful workman; or he may have a faulty way of doing a piece of work.

A learner should exercise caution and common sense in copying the methods of another. Study the mechanical principles involved in the several parts that go to make up a watch. Compare the different methods of doing work that come under your observation, and strive to devise better methods. Experimentation is the best way to positively determine the value of an idea or method. The learner should devote a portion of his time to experimenting. It will be found that experimentation holds many surprises for the mechanic. He sometimes takes great pains to avoid a difficulty that has no existence outside of his own imagination; or he finds himself confronted with an obstacle that he never suspected. Then again, he may discover what is to him a new law governing some particular feature. Two laws governing the action of a mainspring were thus discovered. These laws are: The difference in the number of coils when a spring is wound up and when it is let down exactly equals the number of turns the barrel will give. When a mainspring covers one-half the *area* of the barrel outside the barrel arbor hub, it will give the greatest number of turns that it is possible to secure from a mainspring of that thickness.

Perhaps there is no part of a watch more neglected than the mainspring. Many use imitation springs which are too soft, in order to avoid breakage. Such springs will become set which is worse than breakage. The mainspring is the source of power. If this most important part is not in proper condition and properly proportioned to the rest of the mechanism, close rating is an impossibility; yet how careless many workmen are about the condition of a mainspring! Some men boldly assert that they do not remove the mainspring from the barrel when cleaning a watch! This prevents their knowing that the spring is not kinked,

crowned or set. What assurance have such men that the mainspring is not in bad condition? The time lost in attempting to regulate one such watch will pay for a dozen springs. A reason given by many watchmakers for not removing the mainspring is the liability of breaking that may ensue. This liability should be an incentive to its removal. The fact that it breaks while being removed or replaced, or even soon after, is proof positive that it was not in good condition. The mainspring is in a constant state of tension. The strain of its dilation and contraction is extreme. This eventually results in what is known as metal fatigue, the result of which is that it either sets or breaks. The useful life of a mainspring is therefore limited, and the fact that it breaks after being removed and replaced is an indication that it had reached the end of its usefulness.

Is it not much better for the repairer to replace the mainspring, even though he gets no pay for the spring, than it is for him to send it out with a spring that is pretty apt to break in a short time afterwards? If he replaces the spring he can generally get paid for it by exhibiting the old spring to the owner of the watch and explaining its condition, whereas, if he lets it go, he is very likely to get the blame for its breakage.

If the spring is in good condition there is no danger to be apprehended as a result of taking it out and cleaning it, provided care is used to avoid putting any extra strain upon it. Some workmen in removing a spring from a barrel grasp the inner end with pliers and pull it upwards. This is a bad practice. A spring may be removed by using a mainspring winder, or a small screwdriver may be inserted under the inner coil and moved along carefully until the spring is released.

A danger presents itself in removing a spring, which is the liability of the barrel to be thrown out of the watchmaker's hands by the force of the spring. This can be avoided by protecting the barrel with the left hand, allow-

ing the hand to completely surround it. Whenever it escapes from the hand accidentally, do not neglect to examine the teeth in order that if any of them are injured by coming in contact with some object, it may be discovered and remedied.

A bad practice in replacing the mainspring is that of inserting the mainspring brace first, then backing the spring into the barrel. This subjects it to undue and unnecessary strain. A spring subjected to this treatment will generally show, if released, distortion—crowning—that produces great friction of its edges against the bottom of the barrel chamber and the under side of the cover. Letting a screwdriver slip over the edges of the coils when removing the barrel cover nicks the edges of the spring. A nicked spring soon breaks at the nicks.

Watchmakers often use mainsprings of inferior quality because of their low price. There is no economy in doing so. A poor spring is apt to entail much more cost in regulating than the difference in price between it and a high grade article.

When a mainspring of poor quality is used and it fails to impart a good motion to the balance, it is a common practice to replace that spring with a stronger one, which of course means one of greater thickness. This involves taking the watch apart again, which costs money. In many cases the thicker spring fills the barrel to such an extent that the watch runs down in 30 hours or less after winding. This causes too much difference between the power delivered when first wound and that at the end of a 24-hour run, the result being an unevenness of rate. The proportions of a spring should in no case be such as to run down in less than 34 hours—40 or over will produce better results.

To secure the maximum efficiency from a spring it should cover exactly half the *area* of the barrel, exclusive of the

barrel arbor. If it falls short, or exceeds, this amount the number of turns given in either case will be lessened.

JEWELS.—The proper treatment of jewels is a matter that is sadly neglected. A just appreciation of the delicacy of jewel bearings is lacking on the part of many watchmakers. This is manifested by the large percentage of the watches sent in for repairs that give evidence of the balance and other jewels (particularly those having endstones), having been subjected to ill-treatment and neglect. Some watchmakers do not remove balance jewels having endstones, when cleaning a watch. They will peg out the jewel without removing the endstone, which serves no good purpose. At best, it only removes the oil from the hole jewel, leaving the viscid oil adhering to the upper side of the jewel and to the endstone. Adding fresh oil to the jewel dissolves this glutinous matter which, becoming mixed with the fresh oil, thickens it and pulls down the motion of the watch.

Where jewels have been removed the settings sometimes give evidence of having been pushed out and pushed back with the points of tweezers or some other pointed instrument. The evil of this practice, to say nothing of the disfigurement, is that when a balance hole jewel is subjected to this treatment, the burrs raised by the pointed instrument used prevent the endstone from being pushed home, thus increasing the balance endshake and separating the jewel and endstone so much that the oil flows away from the jewel hole, and the pivots soon run dry. A balance jewel and endstone should be from one to two hundredths of a millimeter apart. When the upper side of the balance jewel is convex, capillary attraction will retain the oil around the balance pivot until the last atom is exhausted, provided the distance is not greater than that specified. Another evil resulting from a marred jewel setting is that the endstone may be thrown out of flat, thus impairing the rate of the watch.

FITTING A BALANCE STAFF.—Much damage results with incompetent and careless workmen, by their treatment of the balance staff. Driving out a broken staff without in some way relieving it from the staking is a reprehensible practice. Some watchmakers drive the staff out without any attempt to remove that portion which has been spread over the balance arm in staking. The result of this practice is that this spread portion in being driven through invariably enlarges the hole in the balance arm. When a balance staff procured from a factory is inserted into the enlarged hole it does not fit, and by the time it is staked sufficiently to hold, the balance will have been knocked out of shape to such an extent that it will be found difficult to true it. As a matter of fact, the man who does that sort of work rarely trues a balance—possibly because the operation is beyond him. When he attempts to poise it, like as not he will do so by filing the ends of the screws.

Many workmen turn off the staking before driving out the staff, but a much better plan is to turn down the hub and drive out the staff from the lower side. This method will often save much time in truing and poising.

The ill-provided and careless workman is quite likely to injure a watch by improper methods for securing correct sideshake and endshake. It is often found that the pivot is much too small for the jewel. Sometimes where the pivot would not enter a crude attempt has been made to reduce it, the reduction being made with an oilstone or some other sharp cutting device; indeed this is often done without the use of a lathe of any kind, leaving the balance pivot more like the end of a wire nail than a pivot.

In securing endshake other bad practices are used. One of these is to insert a strip of paper under the balance cock the increase or decrease of endshake being produced by inserting the paper under the front or rear end of the balance cock. This is an unworkmanlike prac-

tice, but not as bad as that of digging into the plate with a knife or the point of a graver, raising burrs for the underside of the balance cock to rest upon. To reduce the endshake these burrs are raised at the back end of the cock, to increase it at the front end. I do not wish to be understood as giving directions for accomplishing this butchery, but explain so that they may be recognized when met with in inspecting while taking down the watch. Instances sometimes occur where the underside of the balance cock has been filed—and badly filed at that—to reduce the endshake. This sort of mutilation deserves to be made a criminal offense.

The atrocities perpetrated on the balance, hairspring and escapement are positively infamous. Balances are weighted up with roughly filed pins cut off with cutting pliers. The rims are sometimes twisted out of shape and into kinks that render truing an impossibility. Hairsprings are distorted with all sorts of mutilation. Roller pins are replaced by metal and sometimes by glass. Round pins are found where flat faced ones should be used and the bankings are open to allow them to pass out of the fork slot. The fork slot is often wretchedly filed to admit a larger pin than originally used. Great carelessness is manifested in selecting jewel pins of the correct shape and size. The loss of power thus entailed renders it impossible to secure a good motion or a steady rate.

Opening the bankings seems to be a panacea for all derangements of an escapement. At least, it is so considered by some, so-called, watchmakers.

The foregoing is intended to present the matter of bad workmanship as we see it in the factory hospitals in all its deformity, in the hope that the members of our honorable craft may be thereby induced to take steps toward bringing about a much needed reformation.

It requires years to become a good watchmaker. No man can justly call himself a watchmaker unless he has a thorough knowledge of the construction, function and adjustment of every member entering into the mechanism of a watch and will see that no botch work is permitted. He should possess the ability to reproduce almost any part as perfectly as the original. A long step in this direction would be to institute state boards of examination, with authority to issue certificates to such as were found competent to properly repair watches. The possession of such a certificate would be an assurance to an employer, and might be placed in a conspicuous position in any jewelry establishment as a guarantee to patrons that their watches brought in for repair would be placed in the hands of competent workmen.

This would tend to bring our art to a higher plane. It would secure prices for work more in keeping with the skill required for performing it properly.

The incompetent workman can never be wholly eliminated, but this method would have a decided tendency to cause him to equip himself better, or, in the event of his failure to do so, to relegate him to his proper position.

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